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Fertile and Peraluminous Granites and Related Rare-Element Mineralization in Pegmatites, North-Central and Northeastern Superior Province, Ontario

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Fertile and Peraluminous Granites and Related Rare-Element Mineralization in Pegmatites, North-Central and Northeastern Superior Province, Ontario

by

F.W. Breaks, J.B. Selway and A.G. Tindle

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Miscellaneous Release—Data 210 (Tindle, Selway and Breaks 2006) published separately

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Table 12. Bulk rock compositions of internal units of the Case rare-element pegmatite group and the Case batholith, Cochrane area.

Miscellaneous Release—Data 210

Electron Microprobe and Bulk Rock and Mineral Compositions of Barren and Fertile Peraluminous Granitic Rocks and Rare-Element Pegmatites, North-Central and Northeastern Superior Province of Ontario

by A.G. Tindle, J.B. Selway and F.W. Breaks

This digital release contains all compositional data produced by a 2002 regional investigation of rare-element pegmatites and proximal barren and fertile granitic rocks in parts of the Wabigoon, Quetico and Opatica subprovinces. The data set comprises 9781 electron microprobe, 196 bulk rock and 98 bulk mineral compositions. In addition, colour versions of 56 photographs and 32 figures from OFR 6195, *Fertile Peraluminous Granites and Related Rare-Element Mineralization in Pegmatites, North-Central and Northeastern Ontario*, are provided in tagged image format (*.tif*) files. Location information, tables and probe data are presented as Microsoft® Excel (*.xls*) spreadsheets (49 files). There is also a Microsoft® Access (*.mdb*) file of microprobe analyses. Location data are provided in the Universal Transverse Mercator (UTM) projection and grid system, Zones 16 and 17, North American Datum 1983 (NAD 83). Available on 1 CD-ROM.

This MRD is available separately from the report.

Abstract

This study marks the second regional investigation of mineralization associated with rare-element pegmatites and related S-type, peraluminous granites in the Superior Province of Ontario. The area examined in north-central and northeastern Ontario has had no previous, systematic geological and mineralogical work directed at this deposit-type. The mineral and petrochemical database developed in this study includes 10 155 electron microprobe compositions of important pegmatite minerals, 196 bulk rock and 118 bulk mineral (potassium feldspar, muscovite and beryl) compositions. Rare-element pegmatites and chemically evolved, S-type, peraluminous granite and pegmatitic granite in the Superior Province are most commonly found in the boundary zones between high-grade metasedimentary-rich subprovinces, such as the Quetico and the English, and adjoining greenstone-belt-rich subprovinces, such as the Uchi, Wabigoon and Abitibi. Several lithium-rich, complex-type rare-element pegmatites occur in the study area and include the North and South Aubry, Swole Lake, Superb Lake, Lowther Township and Case pegmatites. Beryl-type rare-element pegmatites were discovered during the present survey at 4 localities: North Jackfish Road and Ketchican Road occurrences in the Armstrong pegmatite field, and the Clavet Township and Shetland Township pegmatites in the Hearst area. S-type, peraluminous pegmatitic granites are widespread in the Hearst area of the Quetico Subprovince and several exposures demonstrated a degree of chemical evolution similar to fertile granites elsewhere in Ontario. Such pegmatitic granites were found in the Pagwachuan River area, and in McCrea, Pelletier and Shetland townships. Exploration for rare-element pegmatite deposits is accordingly recommended for the following areas:

1. English River–Wabigoon subprovincial boundary zone
    - area around the Seymour Lake pegmatite group (Aubry spodumene-subtype pegmatites)
    - area around Swole Lake pegmatite boulder field (lepidolite-subtype pegmatite)
    - area around North Jackfish and Ketchican Road beryl-type pegmatites
    - area adjacent to the Superb Lake spodumene-subtype pegmatite and Abamasagi Lake beryl-type pegmatitic granites
    - Maytham–Queenston lakes peraluminous granite pluton
2. Wabigoon–Quetico subprovincial boundary zone
    - Pagwachuan River area (beryl-type pegmatites)
3. Quetico Subprovince interior
    - Pelletier Township pegmatitic granites
    - McCrea–Shetland pegmatitic granite zone
4. Opatica–Abitibi subprovincial boundary zone
    - area around Case pegmatite group

Recommended exploration techniques to utilize in the above target zones include mineralogical and petrochemical detection of fertile, peraluminous parent granites coupled with regional sampling aimed at discerning exomorphic dispersion in the host rocks adjacent to rare-element pegmatites. Detection of fertile granite and pegmatitic granite, which potentially spawned rare-element pegmatite swarms, is effectively undertaken by evaluation of indicator mineral chemistry (potassium feldspar, muscovite, garnet and tourmaline).

Fertile and Peraluminous Granites and Related Rare-Element Mineralization in Pegmatites, North-Central and Northeastern Superior Province, Ontario

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Introduction

This report represents a synthesis of work initially conducted in 2002 under Operation Treasure Hunt (Breaks, Selway and Tindle 2002). Focus of the current project is on the north-central and northeastern parts of the Superior Province where little existing data are available on the field characteristics, mineralogical and geochemical features of peraluminous pegmatitic granites and rare-element mineralization (Figure 1).

Several significant results emerged from the current study:

- Follow-up examination of the tantalum-rich, North and South Aubry pegmatites and reclassification as complex-type, spodumene-subtype
- Investigation of the newly discovered Swole Lake lepidolite-spodumene pegmatite boulder field that contains amongst the most highly evolved manganotantalite of any rare-element pegmatite in Ontario
- Significant rare-element (Rb, Li, Cs, Sn, Ta, and Nb) lithochemical dispersion halo detected in Onaman–Tashota greenstone belt on North Jackfish Road and near Crescent Lake pegmatite group

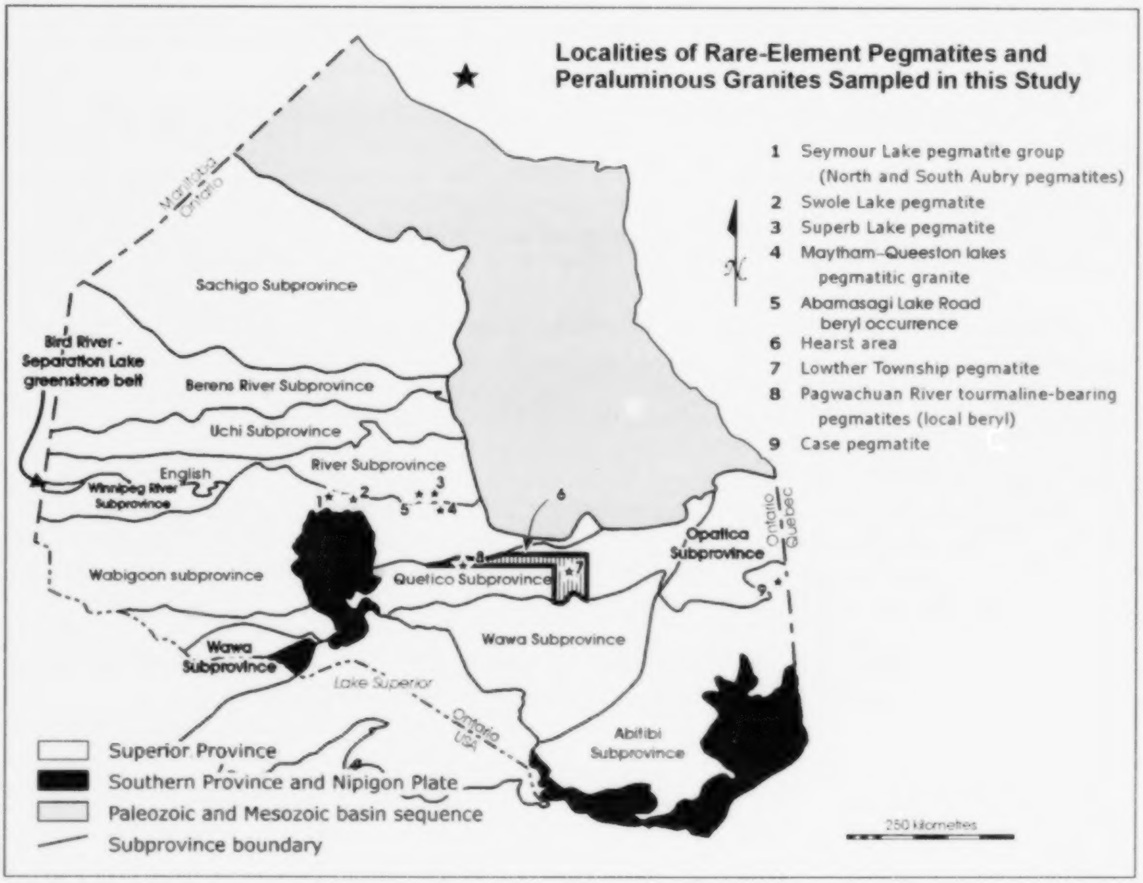
Localities of Rare-Element Pegmatites and Peraluminous Granites Sampled in this Study
1 Seymour Lake pegmatite group (North and South Aubry pegmatites)
2 Swole Lake pegmatite
3 Superb Lake pegmatite
4 Maytham–Queeston lakes pegmatitic granite
5 Abamasagi Lake Road beryl occurrence
6 Hearst area
7 Lowther Township pegmatite
8 Pagwachuan River tourmaline-bearing pegmatites (local beryl)
9 Case pegmatite
N
Manitoba
Ontario
Sachigo Subprovince
Bird River - Separation Lake greenstone belt
Berens River Subprovince
Uchi Subprovince
English River Subprovince
Winnipeg River Subprovince
Wabigoon subprovince
Quetico Subprovince
Opatica Subprovince
Ontario
Quebec
Wawa Subprovince
Wawa Subprovince
Lake Superior
Ontario
USA
Abitibi Subprovince
Superior Province
Southern Province and Nipigon Plate
Paleozoic and Mesozoic basin sequence
Subprovince boundary
250 kilometres

Figure 1. Location of peraluminous pegmatitic granite masses and rare-element pegmatite mineralization examined in this study.

- Detailed investigation of the Superb Lake rare-element pegmatite, north of Nakina and consequent classification as complex-type and spodumene-subtype
- Discovery of new rare-element pegmatite mineralization of the beryl-type: North Jackfish Road and Ketchican Road (Armstrong area); Abamasagi Road (Nakina area), Shetland Township (Hearst area) and in the Pagwachuan River area
- Detailed investigation of the Lowther Township rare-element pegmatite (Hearst area) and classification as complex-type and lepidolite-subtype
- Detailed investigation of the Case pegmatite group in the (Cochrane area) and classification as complex-type, spodumene-subtype

A total of 196 bulk whole rock, 81 bulk potassium feldspar and 37 bulk muscovite samples were analyzed by the Geoscience Laboratories, Ontario Geological Survey, Sudbury, Ontario. Fertile granites, aplite, metasomatized host rocks, potassium feldspar and muscovite were analyzed by bulk chemical techniques.

This study is also supported by 9412 electron microprobe analyses undertaken by A.G. Tindle at The Open University and 743 garnet analyses at the Geoscience Laboratories for a total of 10 155 analyses. The microprobe compositions include tantalum-niobium oxide minerals (i.e., ferrocolumbite, ferrotantalite, manganocolumbite, manganotantalite, microlite and ferrotapiolite), cassiterite, tourmaline (schorl, dravite and elbaite), garnet, fluorapatite, beryl, potassium feldspar, micas (zinnwaldite, lepidolite and muscovite), spodumene, lithiophilite and tantalian rutile.

All of the bulk rock and mineral composition and electron microprobe analyses of samples collected in the summer of 2002 are available on Miscellaneous Release—Data (MRD) 210 (Tindle, Selway and Breaks 2006). All tables in this report are included in MRD 210. However, the bulk rock and mineral composition tables (Tables 4, 5, 8 and 12) are only included on MRD 210. Colour versions of all photos in this report can be found in MRD 210. The figures are also included on MRD 210; many of the mineral plots are in colour.

Most sample sites given in the text (e.g., 02-FWB-41) can be located on Figures 3, 24 and 26, which can be found in the back pocket of this report. Locations for all sample localities in this report are provided using Universal Transverse Mercator (UTM) co-ordinates in North American Datum 1983 (NAD83); a detailed list of locations for each of the 3 study areas can be found in the file "UTM-NAD83 co-ordinates for localities" on MRD 210 (Tindle, Selway and Breaks 2006).

Several tables of reference information are provided at the end of the report: definitions of common pegmatite terms (Appendix 1), conversion from ppm to element % to weight % for rare-elements (Appendix 2), formulae for pegmatite minerals examined during this study (Appendix 3) and the physical properties of pegmatite minerals (Appendix 4).

For an overview of exploration techniques applied to fertile granites and rare-element pegmatites, *see* Breaks, Selway and Tindle (2003a) and Selway, Breaks and Tindle (2006).

Wabigoon–English River Subprovincial Boundary Zone (Armstrong Area)

The Wabigoon–English River subprovincial boundary zone contains rare-element mineralization distributed over a 130 km strike length between the Linklater Lake pegmatite dikes (beryl-columbite-subtype) and the Superb Lake pegmatite near Nakina (spodumene-subtype), north-central Ontario (Figure 2). The locations of bulk and electron microprobe compositions for this area can be found in Figure 3 (back pocket).

Most of the pegmatites in this boundary zone are hosted by mafic metavolcanic rocks (medium metamorphic grade) of the Wabigoon Subprovince. There are 2 exceptions to this host-rock context—the Linklater Lake pegmatite dikes and the Superb Lake pegmatite—both of which are contained in medium-grade, unmigmatized metawacke of the English River Subprovince (Breaks, Selway and Tindle 2002, 2003a). Lepidolite-subtype pegmatite boulders at Swole Lake are also hosted by unmigmatized metawacke, but the derivative outcrop has yet to be identified (Breaks, Selway and Tindle 2002).

This subprovincial boundary zone is characterized by complex-type, spodumene-subtype pegmatites in which the Ta-Nb oxide mineral population is dominated by tantalum-rich manganotantalite (Tindle, Selway and Breaks 2002; Breaks, Selway and Tindle 2003a). The average Ta_2O_5 contents in manganotantalite from lithium-rich pegmatites in this boundary zone are given in Table 1.

NORTH AND SOUTH AUBRY PEGMATITES

The North and South Aubry complex-type, spodumene-subtype pegmatites are located 59 km northeast of Armstrong and 2.7 km west of Seymour Lake along a prominent ridge that has approximately 100 m of local relief. These pegmatites comprise a series of stacked, flat-lying sills that dip shallowly to steeply

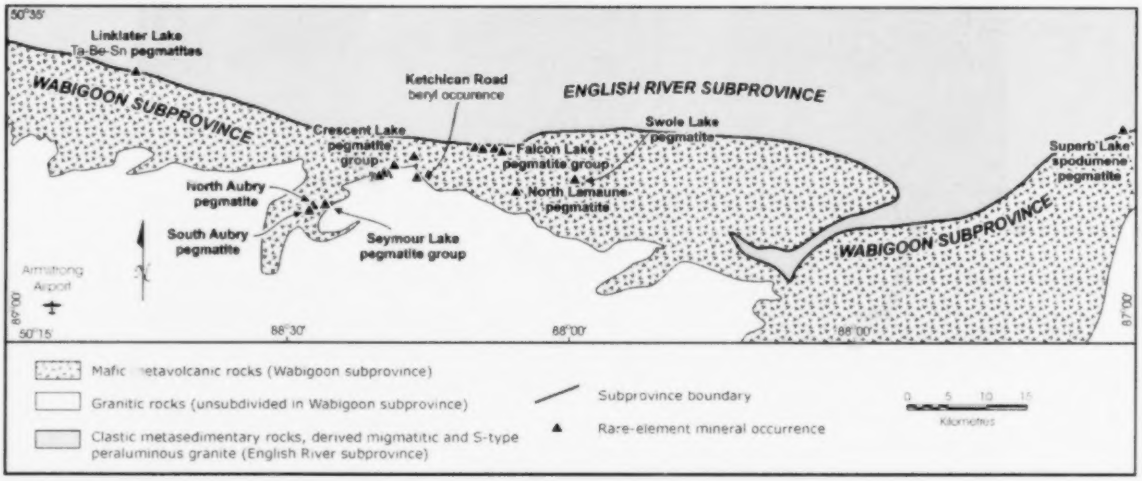
50°35'
Linklater Lake
Ta-Be-Sn pegmatites
WABIGOON SUBPROVINCE
Ketchican Road
beryl occurence
ENGLISH RIVER SUBPROVINCE
Crescent Lake
pegmatite
group
Falcon Lake
pegmatite group
Swole Lake
pegmatite
Superb Lake
spodumene
pegmatite
North Aubry
pegmatite
North Lamaune
pegmatite
South Aubry
pegmatite
Seymour Lake
pegmatite group
WABIGOON SUBPROVINCE
Armstrong
Airport
N
89°00'
50°15'
88°30'
88°00'
88°00'
87°00'
Mafic metavolcanic rocks (Wabigoon subprovince)
Granitic rocks (unsubdivided in Wabigoon subprovince)
Clastic metasedimentary rocks, derived migmatitic and S-type peraluminous granite (English River subprovince)
Subprovince boundary
Rare-element mineral occurrence
0
5
10
15
Kilometres

Figure 2. General geological location of rare-element mineralization situated in the English River–Wabigoon subprovincial boundary zone in the Armstrong–Nakina area (geology generalized *after* Parker and Stott 1998).

Table 1. Average Ta_2O_5 contents in columbite-tantalite from lithium-rich, rare-element pegmatites of the Armstrong pegmatite field

Rare-Element Pegmatite	Mean Ta_2O_5 (weight %)
Tebishogeshik pegmatite group (sodic aplite unit)	63
Falcon Lake spodumene pegmatite	68
South Aubry pegmatite (albite-spodumene layer)	68
Swole Lake boulder field (lepidolite-subtype pegmatite)	69
North Aubry pegmatite (inner core zone)	81

east and intruded mafic metavolcanic rocks of the Wabigoon Subprovince at 2666±6 Ma (F.W. Breaks, OGS, unpublished data, 2006). This aspect is best observed in Trench NA-5 where flat-lying, thin sheets (Photo 1) and erosional remnants are well exposed. The stacked nature of the pegmatites was verified by a diamond-drilling program by Linear Resources Inc., now known as Linear Gold Corporation (Linear Resources Inc., news release, August 26, 2002).

The main body of the North Aubry pegmatite ranges in true thickness from 13 to 25 m over a minimum strike length of 260 m (Figure 4; Dimmell and Morgan 2006, p.50). The South Aubry pegmatite, situated 500 m south, is flat lying with a true thickness between 4.1 and 16.3 m over a minimum strike length of 225 m (Dimmell and Morgan 2006, p.54).

The North Aubry pegmatite is characterized by large spodumene crystals (up to 1.4 m long), coarse manganotantalite (up to 3.5 by 5 cm) and abundant blocky potassium feldspar. The South Aubry pegmatite contains striking, plumose quartz-muscovite intergrowths, exceptionally coarse, green beryl (up to 46 by 34 cm) and abundant albite. The most obvious difference between the 2 pegmatites is the much greater abundance of muscovite in the South Aubry pegmatite.

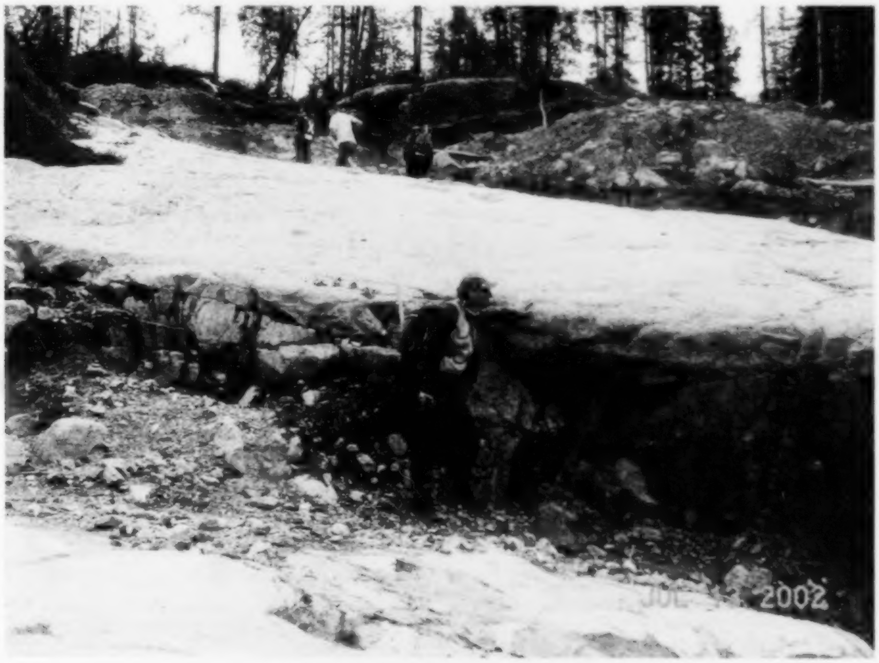

Photo 1. View of flat-lying, zoned pegmatites in Trench NA-5 of the North Aubry pegmatite. Arrow points to underlying mafic metavolcanic rocks.

Exploration for tantalum by Linear Gold Corp. was initially undertaken by the excavation of 7 trenches in the North Aubry pegmatite (Figure 4) and 3 trenches in the South Aubry pegmatite (*see* Figure 13). The trenches constitute areas of heavy machinery stripping in which overburden removal has exposed bedrock. Trench SA-5 (*see* Figure 13) was interpreted by Linear Gold Corp. to represent part of the South Aubry pegmatite; however, geological and mineralogical data from this study indicate that it is more likely part of the North Aubry pegmatite. Linear Gold Corp's Trench SA-4 (*see* Figure 13), near the southern limit of the South Aubry pegmatite, actually does not expose bedrock, but significantly contains a lepidolite-rich pegmatite boulder with 0.054 weight % Ta_2O_5 (Dimmell and Morgan 2006). The highly evolved mineralogy (lepidolite, wodginite, pollucite and manganotantalite) more closely resembles the Swole Lake pegmatite rather than the North and South Aubry pegmatites.

Linear Gold Corp. also conducted a diamond-drilling program to delineate the pegmatite system and to define grade and tonnage of the tantalum mineralization (Linear Resources Inc., news release, August 26, 2002). Several unexposed pegmatites were intersected at depth in the diamond drilling. The widest spodumene pegmatite intersected has a 4 to 5 m true thickness situated approximately 50 m below the western margin of the North Aubry pegmatite. Another 4 to 5 m thick, spodumene pegmatite was intersected by diamond drilling about 25 to 40 m below the South Aubry pegmatite. Stacked pegmatites with estimated true thicknesses from less than 1 to 8 m were also intersected below Trench SA-5 (*see* Dimmell and Morgan 2006, p.54). Tantalum contents in grab, channel and diamond-drill core from the drilling program of Linear Gold Corp. from the North and South Aubry pegmatites are summarized in Table 2. A generalized plot of all data for the North and South Aubry pegmatites is shown in Figure 5.

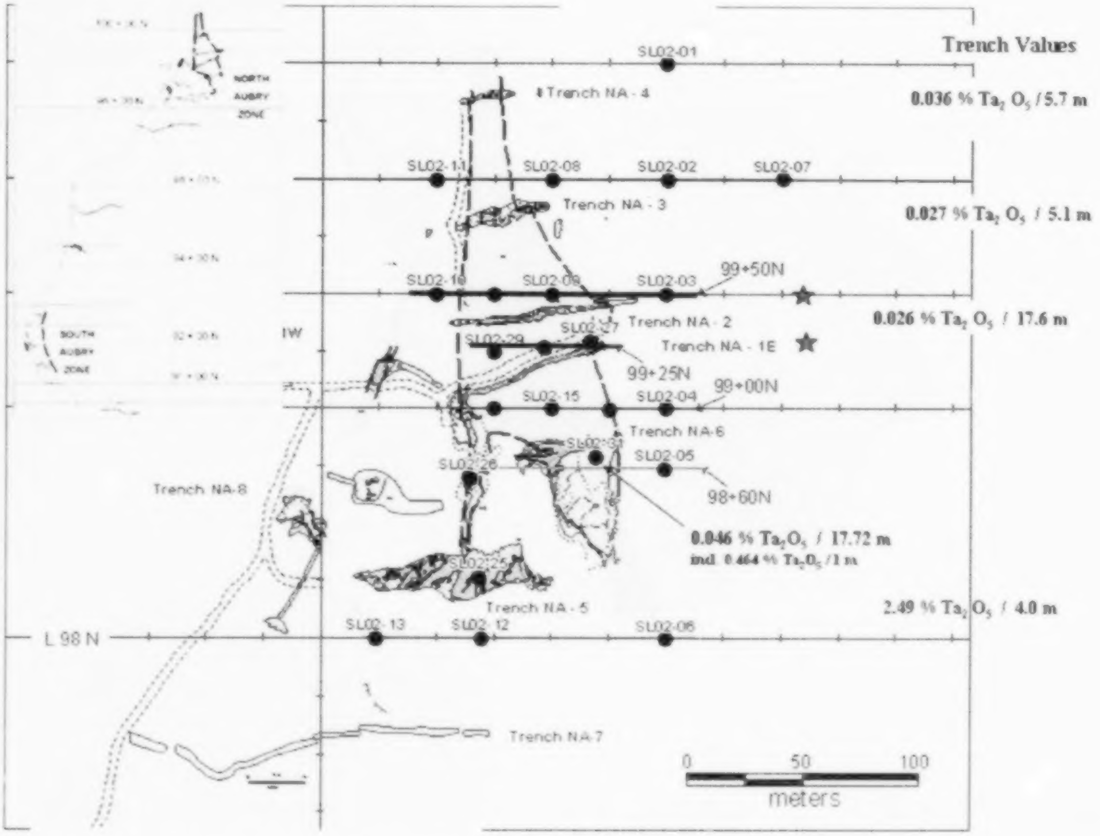
Trench Values
NORTH AUBRY ZONE
SOUTH AUBRY ZONE
SL02-01
Trench NA - 4
0.036 % Ta_2O_5 / 5.7 m
SL02-11
SL02-08
SL02-02
SL02-07
Trench NA - 3
0.027 % Ta_2O_5 / 5.1 m
SL02-10
SL02-09
SL02-03
99+50N
0.026 % Ta_2O_5 / 17.6 m
Trench NA - 2
IW
SL02-29
SL02-27
Trench NA - 1E
99+25N
99+00N
SL02-15
SL02-04
Trench NA-6
SL02-31
SL02-05
SL02-26
Trench NA-8
98+60N
0.046 % Ta_2O_5 / 17.72 m
incl. 0.464 % Ta_2O_5 / 1 m
SL02-25
Trench NA - 5
2.49 % Ta_2O_5 / 4.0 m
SL02-13
SL02-12
SL02-06
L 98 N
Trench NA-7
0
50
100
meters

Figure 4. Plan view and location of trenches in the North Aubry pegmatite *from* Dimmell and Morgan (2006).

Table 2. Summary of Ta_2O_5 contents in grab, channel and diamond-drill core samples from the North and South Aubry pegmatites (Dimmell and Morgan 2006).

Pegmatite	Ta_2O_5 Content (weight %)		Sample Reference #
	Channel or Grab Sample	Diamond-Drill Core	
North Aubry		0.010 wt % over 23.9 m	SL-02-27
		0.016 wt % over 5 m	SL-02-27
		0.143 wt % over 1.4 m	SL02-28
		0.035 wt % over 11.8 m	SL-02-28
		0.017 wt % over 12 m	SL-02-29
	2.49 wt % over 4.0 m		
South Aubry		0.18 wt % over 4.1 m	SL-02-24
		0.006 wt % over 7.1 m	SL-02-22
		0.015 wt % over 16.3 m	SL-02-21
		0.019 wt % over 15.1 m	SL-02-20
		0.007 wt % over 15.9 m	SL-02-19
Lepidolite boulder (Trench SA-4)	0.054 wt % in grab sample		

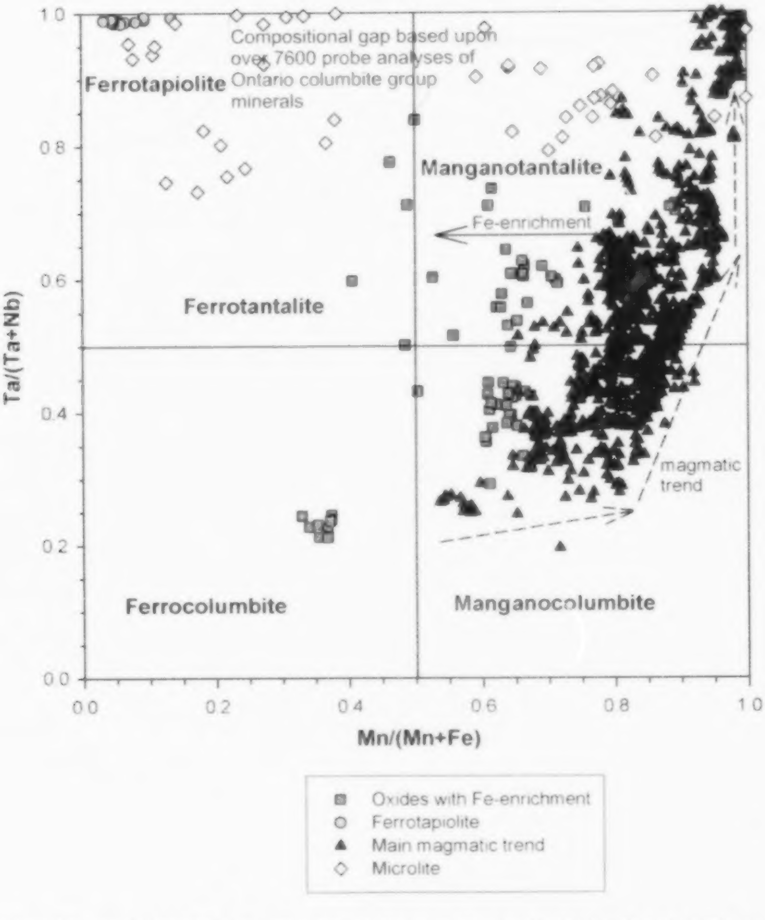

Figure 5. Columbite-tantalite quadrilateral plot (atomic ratios) showing all data for the North and South Aubry pegmatites. Compositional gap between ferrotapiolite and ferrotantalite is based upon 7600 compositions of columbite-tantalite from Ontario. Microlite compositions may plot within this compositional space.

Initial examination of the geology and mineralogy of the North and South Aubry pegmatites was undertaken by Breaks, Selway and Tindle (2001). Breaks, Selway and Tindle (2003a) also documented bulk rock and mineral compositional data from the North Aubry Pegmatite (5 trenches) and the South Aubry pegmatite (3 trenches). Further investigation of the pegmatites in 2002 focussed upon 2 trenches not examined in the previous work and also led to the division of internal pegmatite zones.

Geology of the North Aubry Pegmatite

The North Aubry spodumene-subtype pegmatite is enclosed in mafic metavolcanic host rocks, which comprise massive and pillowed flows metamorphosed to medium metamorphic grade and marked by local calc-silicate segregations of chlorite-epidote-quartz-carbonate. The North Aubry pegmatite is complexly zoned and can be divided into 10 pegmatite units, based on mineral assemblages, from the outermost zone to the pegmatite core.

INTERNAL ZONATION OF THE NORTH AUBRY PEGMATITE

1. quartz-rich border zone (~1 cm thick: Trenches NA-2, between Trenches NA-2 and NA-3, and between Trenches NA-5 and NA-6 (designated herein as NA-2-3 and NA-5-6, respectively))
2. outer sodic aplite zone (sugary albite- or cleavelandite-rich)
3. quartz-coarse muscovite zone
4. muscovite-rich pods
5. quartz-rich pods
6. potassium feldspar zone
7. albite-spodumene zone
8. potassium feldspar-spodumene zone
9. corona zone
10. inner core zone

Quartz-rich Border Zone (1)

The quartz-rich border zone, typically about 1 cm thick, occurs discontinuously along the northern contact of the pegmatite as in Trench NA-2-3. This unit contains a 19 cm long, prismatic, black tourmaline cluster, intergrown with plagioclase and fluorapatite, and represents the coarsest tourmaline observed in the North Aubry pegmatite.

Outer Sodic Aplite Zone (2)

The outer sodic aplite zone (Photo 2), distributed throughout the North Aubry pegmatite, contains abundant quartz and albite, minor fine-grained oxide minerals (manganocolumbite and manganotantalite) and fluorapatite, and localized tourmaline (calcium-bearing schorl-dravite). Albite may occur as fine-grained equant ("sugary") grains or platy crystals known as cleavelandite.

Thicknesses up to 30 cm wide are evident for this zone, as in Trench NA-6, where the rock consists of aplite with minor fine-grained biotite and rare spodumene altered to biotite and hematite. The appearance of spodumene in the aplite, as at Trench NA-6, probably represents a transition between the outer sodic aplite zone and the potassium feldspar-spodumene zone.

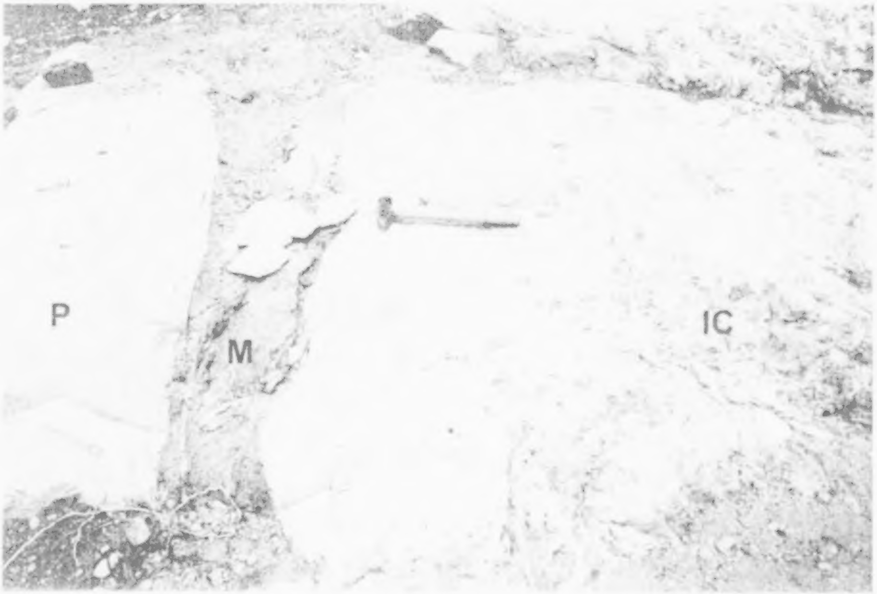

Photo 2. Close-up of pegmatite zones along contact of North Aubry pegmatite in Trench NA-5 showing the outer sodic aplite unit, marked by hammer, that grades into the highly evolved inner core zone (IC). To the left of the hammer is biotite-rich metasomatized mafic metavolcanic rocks (M) intruded by a plagioclase porphyry dike (P) that has a blue coloration due to holmquistic alteration from lithium-bearing pegmatite fluids.

Photo 3. Coarse black manganotantalite and fluorapatite distributed along the contact between a quartz-rich pod and sodic aplite in Trench NA-2.

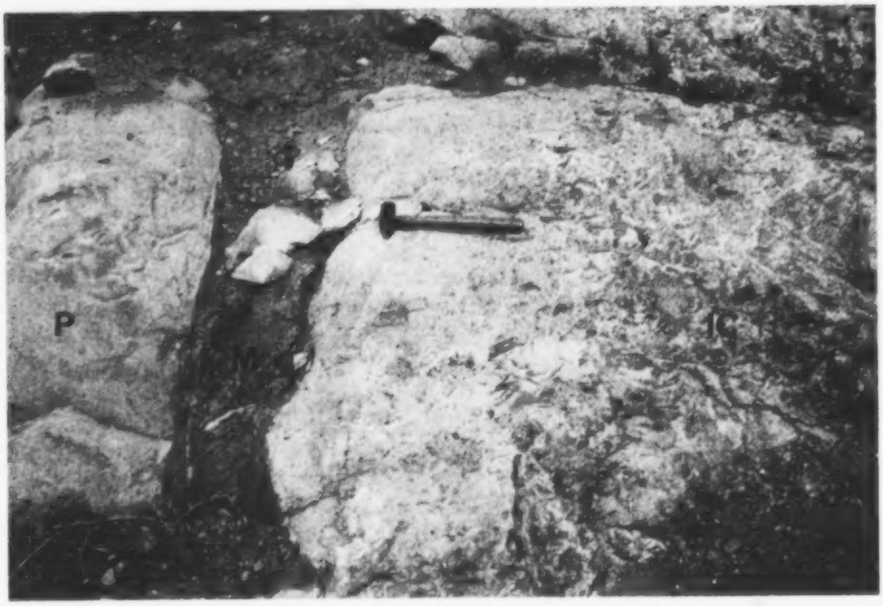

Photo 2. Close-up of pegmatite zones along contact of North Aubry pegmatite in Trench NA-5 showing the outer sodic aplite unit, marked by hammer, that grades into the highly evolved inner core zone (IC). To the left of the hammer is biotite-rich, metasomatized mafic metavolcanic rocks (M) intruded by a plagioclase porphyry dike (P) that has a blue colouration due to holmquistite alteration from lithium-bearing, pegmatite fluids.

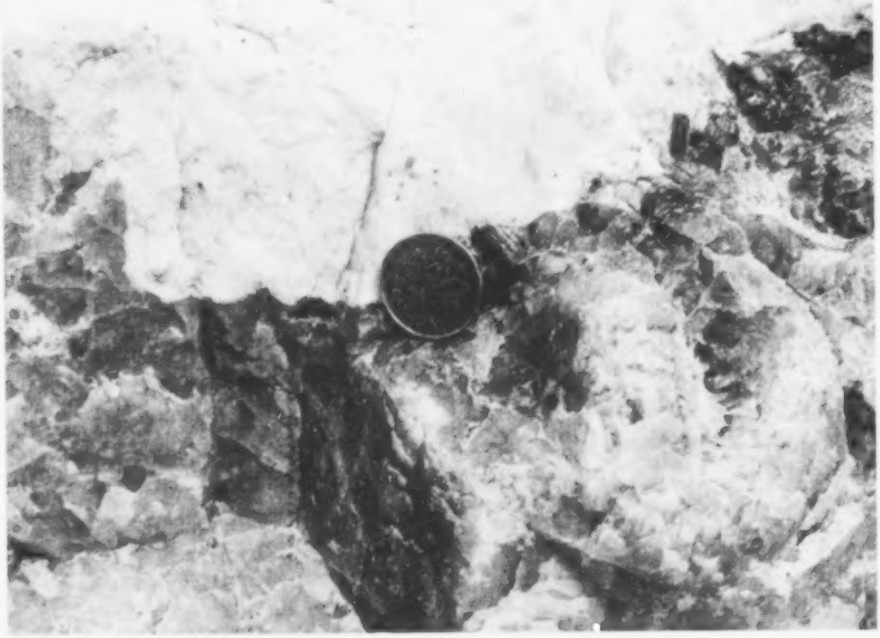

Photo 3. Coarse black manganotantalite and fluorapatite distributed along the contact between a quartz-rich pod and sodic aplite in Trench NA-2.

In the northern part of the pegmatite (Trenches NA-4, NA-2 and NA-2), the zone consists of sugary, albite-rich aplite (Photo 3), whereas, in the albite-spodumene zone, cleavelandite dominates in the aplite units. In the southern part of the pegmatite (Trenches NA-5-6, NA-5 and SA-5), the opposite is evident in which the outer sodic zone consists of cleavelandite-dominant aplite (*see* Photo 2) and the albite-spodumene zone contains sugary albite-rich aplites.

In Trench NA-4, the outer sodic zone contains aplite with minor amounts of garnet (spessartine), molybdenite, green muscovite and white beryl. This is the only occurrence of molybdenite in either the North or South Aubry pegmatites. Minor amounts of black tourmaline occur in Trenches NA-2, NA-3 and the eastern end of Trench NA-5. Black tourmaline occurs along fracture surfaces in connector Trench NA-5-6.

Dike equivalents of the outer sodic zone are sparsely evident as exemplified by a fine-grained, red aplite dike (0.3 to 0.6 m thick) emplaced in mafic metavolcanic rocks near the east end of Trench NA-4.

The contact between primary sodic aplite and an enveloping quartz pod at the eastern end of Trench NA-2 contains notable concentrations of black manganocolumbite crystals, up to 1 cm in length (*see* Photo 3).

Miarolitic cavities, up to 5 by 6 cm in size, occur in cleavelandite-rich aplite of Trenches NA-4 and NA-5 and are mainly lined with cleavelandite crystals with minor muscovite and tourmaline, all of which are coated by a drusy film of hematite. The miarolitic cavities are located close to the contact with the mafic metavolcanic host rocks and contain coarse-grained black tourmaline (1.5 cm long).

Quartz-Coarse Muscovite Zone (3)

The intermediate quartz-coarse muscovite zone is relatively abundant throughout the pegmatite and is found in the following zonation sequence: host rock → outer sodic zone → quartz-coarse muscovite zone → potassium feldspar zone or potassium feldspar-spodumene zone. The quartz-coarse muscovite zone contains minor Ta-Nb oxide minerals (manganocolumbite and manganotantalite), fluorapatite and white beryl (up to 3.5 by 2.5 cm).

Muscovite-rich Pods (4)

The muscovite-rich pods in Trench NA-2, up to 40 cm across, are enveloped by aplite or pink blocky potassium feldspar. The silver, coarse-grained mica in the pods comprise muscovite (95 volume %) with thin lepidolite replacement rims and minor, interstitial quartz and albite (Photo 4). Sparse fluorapatite and Ta-Nb oxide minerals (5 by 5 mm in cross section and up to 7 mm long), which mostly consist of manganocolumbite and manganotantalite, were also observed.

Quartz-rich Pods (5)

Massive quartz-rich pods occur in Trenches NA-3 and NA-2 and in the excavated area between Trenches NA-2 and NA-3 (NA-2-3) (*see* Figure 4; *see* Photo 3). In Trench NA-3, one quartz pod contains 2 separate clusters respectively composed of fine-grained green muscovite aplite, and aplite with dark green spodumene and coarse-grained muscovite.

Photo 4. Muscovite-rich pod in Trench NA-2 partly enveloped by a quartz-rich mass with blocky potassium feldspar.

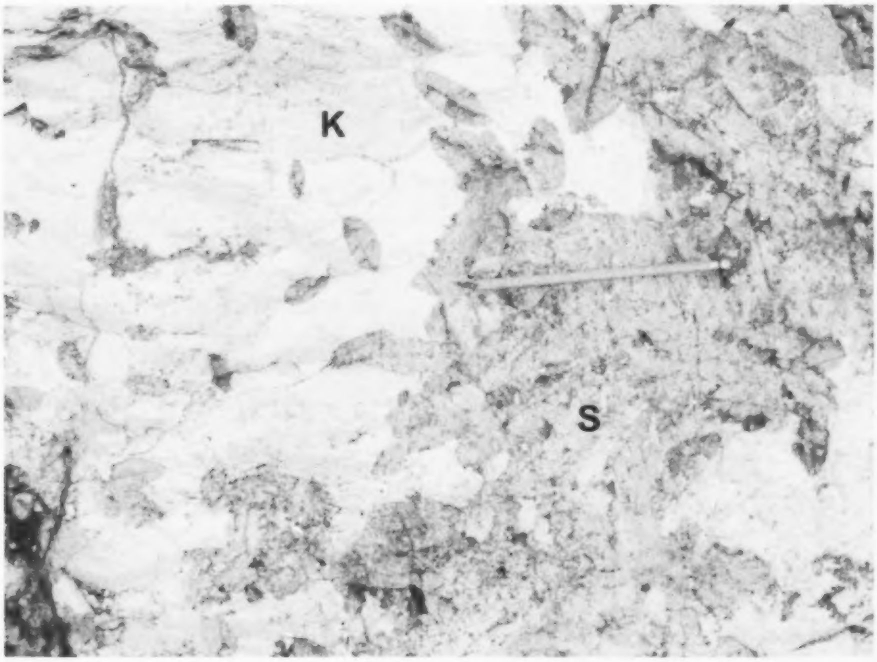

Photo 5. Potassium feldspar zone showing bimodal distribution of potassium feldspar-rich aggregates (K) that grade into a quartz-spodumene-rich mass (S).

Potassium Feldspar Zone (6)

The potassium feldspar zone exhibits petrographic variation and may exhibit unaltered, albitized and hematized potassium feldspar. The unaltered potassium feldspar zone contains peach or white, blocky potassium feldspar, quartz, green muscovite and local spodumene. The quartz and muscovite contents in the potassium feldspar zone vary from nil to 90 volume %. For example, Trench NA-6 contains a large area composed of monomineralic white potassium feldspar, whereas, in Trench NA-2, there is gradation of potassium feldspar-rich segregations into spodumene-quartz masses that are almost entirely devoid of feldspars (Photo 5).

The albitized potassium feldspar zone contains peach coloured, blocky potassium feldspar and is crosscut by veins (up to 10 cm wide) of aplite with fine-grained green muscovite and rare green beryl (12 by 10 cm) and specks of Ta-Nb oxide minerals. The hematized parts of the potassium feldspar zone contain abundant red to pink potassium feldspar and minor, orange lithiophilite ($LiMnPO_4$) with metallic black manganese-stained rims.

Albite-Spodumene Zone (7)

The albite-spodumene zone consists of 2 main units:

zone 7a cleavelandite-rich aplite +spodumene (Trenches NA-4 and NA-6); and
zone 7b aplite with spodumene (Trench NA-5-6)

The cleavelandite-spodumene zone (7a) consists of abundant quartz, minor blue fluorapatite, green beryl, Ta-Nb oxide minerals (manganocolumbite) and potassium feldspar. Spodumene, evident as several coarse green tabular crystals up to 2 m long, reveals parallel alignment that is perpendicular to the pegmatite–host rock contact (Photo 6). Relatively fine-grained spodumene crystals (~20 cm long) are

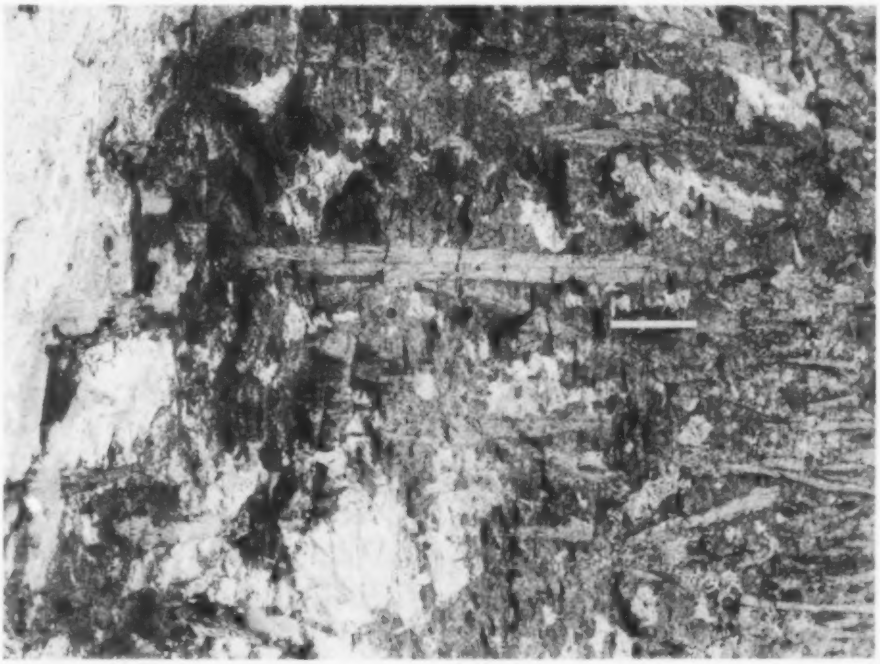

Photo 6. Coarse spodumene crystals aligned normal to nearby host rock contact in the albite-spodumene zone of Trench NA-6.

randomly oriented. The coarse spodumene crystals are partially rimmed and invaded by an assemblage of muscovite, blue fluorapatite and green beryl only along one side of each crystal. Both the coarse and "fine"-grained spodumene crystals locally contain muscovite inclusions. Blue fluorapatite is sparsely abundant in Trench NA-6 and up to 2 cm long.

The aplite-spodumene zone (7b) consists of coarse-grained, green spodumene with interstitial aplite and minor cleavelandite. The coarse green spodumene may be altered to red or black due to an influx of iron that could have arisen by different mechanisms: metasomatic interchange with the host rock, digestion of host rocks or by post-magmatic fluids guided by brittle shears and fractures. The interstitial aplite contains fluorapatite, Ta-Nb oxide minerals (manganocolumbite), coarse muscovite and altered spodumene (fine grained brown and dark green, unidentified secondary minerals).

Potassium Feldspar-Spodumene Zone (8)

The potassium feldspar-spodumene zone represents the most widespread internal unit (Photo 7) and is exposed in most trenches except in the northeast part of Trench NA-4 and in the highly evolved Trench NA-5. This zone contains green, randomly oriented, spodumene, white, blocky potassium feldspar and common, coarse-grained, green beryl up to 19 cm across. Minor phases comprise quartz, muscovite, blue fluorapatite and manganocolumbite and manganotantalite up to 1.5 by 5.5 cm.

Corona Zone (9)

The corona zone and the spatially associated inner core zone display the most striking textures in the entire pegmatite and are only exposed in Trench NA-5. These zones comprise the most chemically evolved part of the pegmatite.

Two types of corona textures are evident: a) euhedral quartz crystals enveloped by radiating cleavelandite, blades of Ta-Nb oxides, and books of purple muscovite and b) green spodumene mantled by radiating cleavelandite, green fluorapatite and oxide needles (manganocolumbite and manganotantalite).

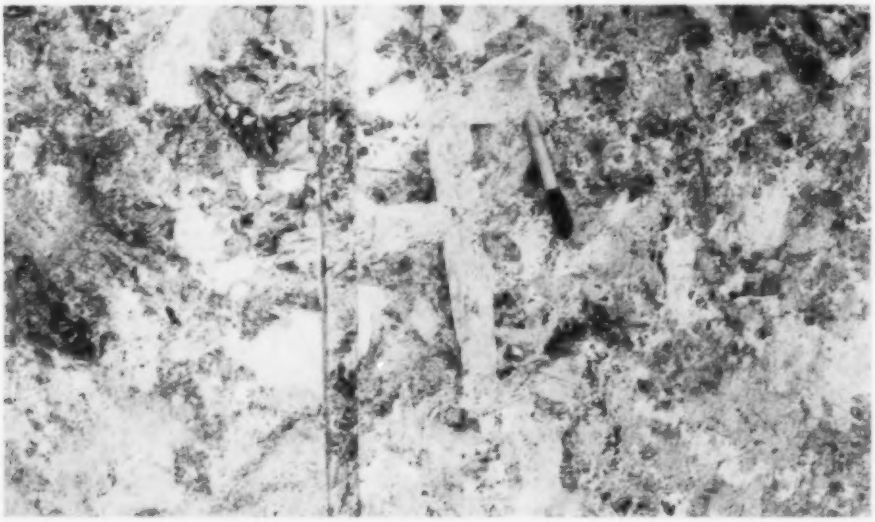

Photo 7. Potassium feldspar-spodumene zone from Trench NA-1 composed of coarse, randomly oriented spodumene crystals, beryl, quartz, albite and irregular megacrysts of potassium feldspar.

The quartz-centred corona is generally spherical in shape, whereas the spodumene-centered corona mimics the tabular spodumene megacrysts (Photo 8). In contrast, individual, very coarse-grained spodumene crystals are not enveloped by cleavelandite in the inner core zone. Tapered spodumene crystals interestingly are oriented across both pegmatite zones with the wider part of elongate crystals situated in the inner core zone and the narrow end embedded in the corona zone. Fine-grained purple mica and albite are interstitial phases in both corona types.

Inner Core Zone (10)

The inner core zone consists of randomly oriented, coarse-grained, green and white spodumene blades that form a box-work texture with interstitial white, primary cleavelandite, quartz, pink cesium-rich beryl and coarse-grained equant manganotantalite (Photo 9). The manganotantalite crystals, up to 5 cm diameter, are the coarsest observed by the authors in any rare-element pegmatite examined in the Superior Province of Ontario.

Cesium-rich beryl is evident as coarse, pale pink crystals with basal sections up to 20 cm in diameter that crystallized within the interstices produced by randomly oriented spodumene blades (Photo 10). The inner core zone also contains minor amounts of purple muscovite and white, blocky potassium feldspar that contains inclusions of spodumene, and rare, orange lithiophilite rimmed by black manganese staining.

Pollucite [$(Cs,Na)AlSi_2O_6 \cdot nH_2O$], a rare cesium-rich mineral, was identified within a 6 by 13 cm, light brown, recessively weathered, crudely rectangular mass that is subtly apparent within the centre of the inner core zone (Photo 11). Part of this mass comprises unaltered pollucite (confirmed by X-ray diffraction), but is transected by narrow veins (0.5 to 1 cm thickness) composed of silver mica, milky albite and an unknown, orange, secondary mineral. Nearby masses mineralogically similar to the veins

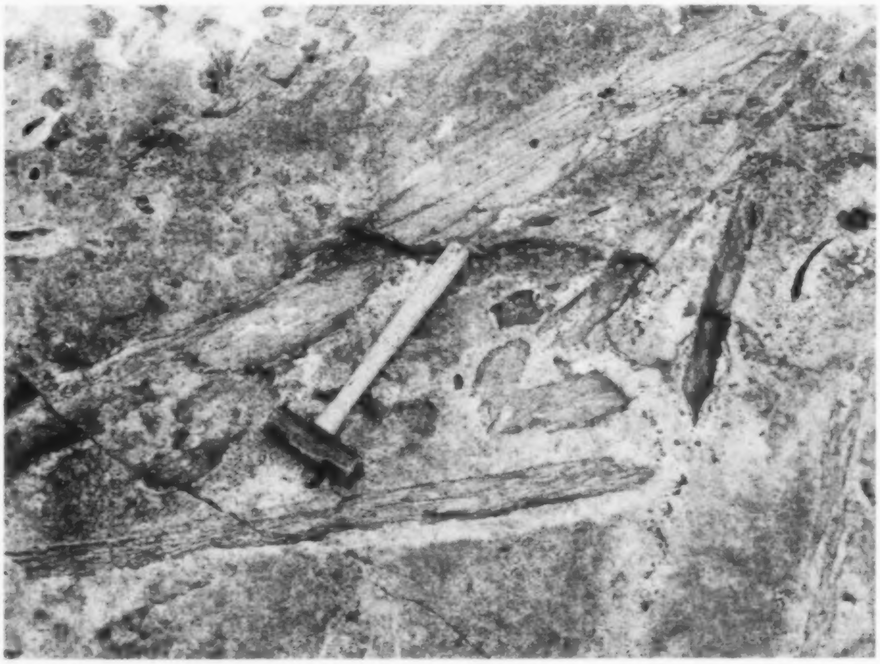

Photo 8. Corona texture produced by tabular spodumene crystals mantled by sodic aplite at Trench NA-5.

Photo 9. Box-work texture typical of the inner core zone marked by randomly oriented spodumene and interstitial quartz, albite and very coarse manganotantalite.

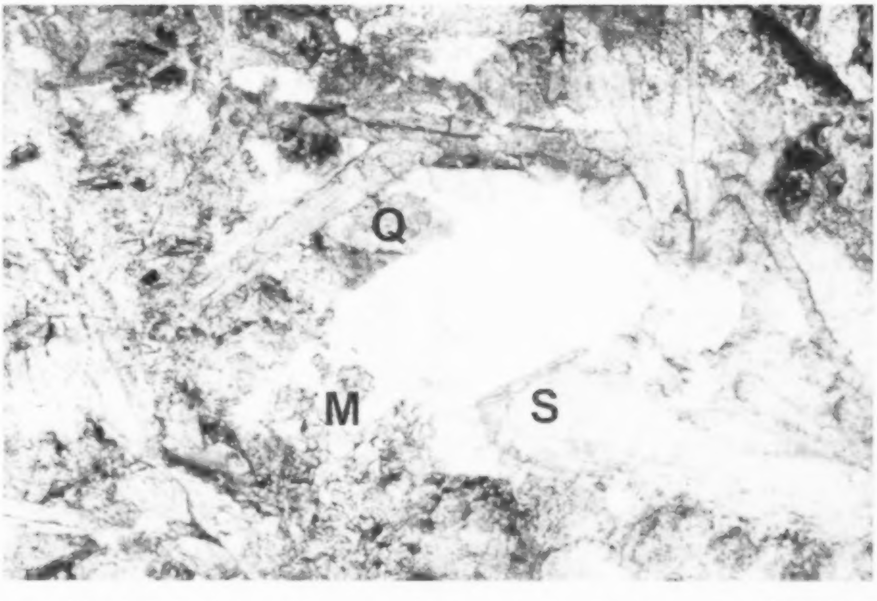

Photo 10. Cesium-rich beryl, marked by coin, that occurs with grey quartz (Q) and purple muscovite (M) within the interstice between earlier, randomly oriented spodumene (S) crystals that are partially stained by hematite.

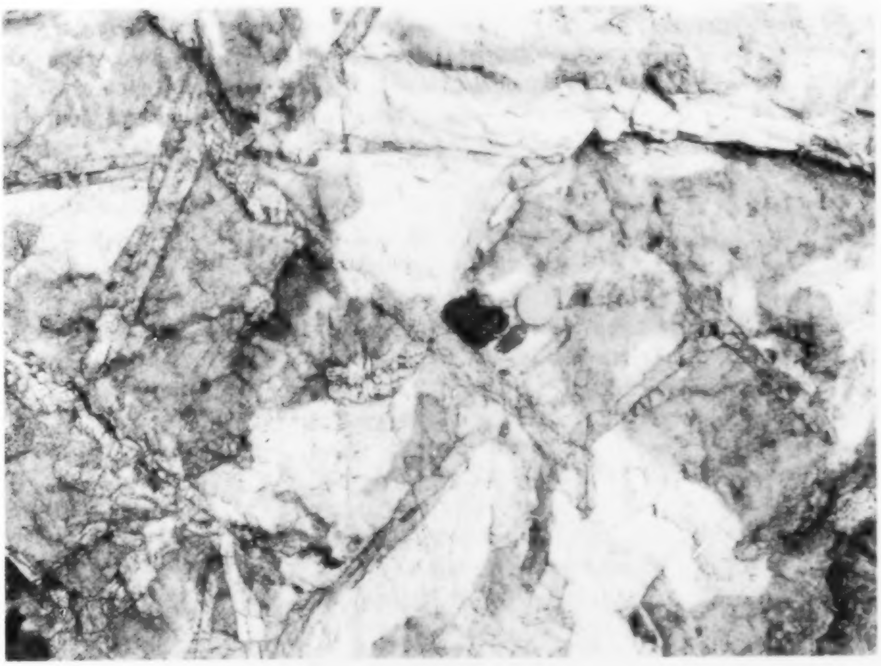

Photo 9. Box-work texture typical of the inner core zone marked by randomly oriented spodumene and interstitial quartz, albite and very coarse manganotantalite.

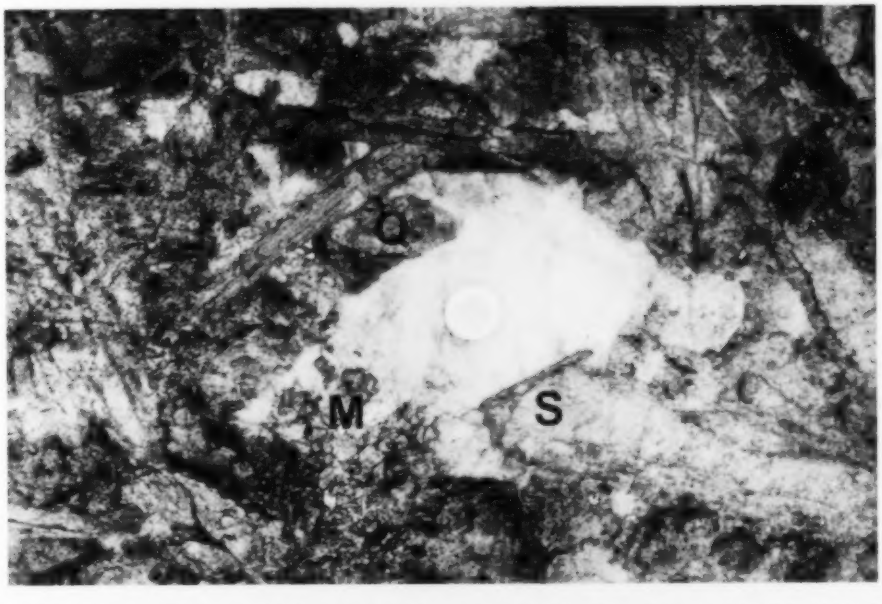

Photo 10. Cesium-rich beryl, marked by coin, that occurs with grey quartz (Q) and purple muscovite (M) within the interstice between earlier, randomly oriented spodumene (S) crystals that are partially stained by hematite.

could represent virtually complete alteration of the former pollucite. White to pink massive adularia (0.14 to 0.23 weight % Rb_2O, up to 0.06 weight % Cs_2O) occurs as an alteration product of pollucite. Adularia is a habit of potassium feldspar that typically forms at a low temperature. There is also an unidentified very fine-grained, yellow green alteration phase that is associated with the mica veinlets or developed along the outer grain margins of the pollucite.

This pollucite occurrence is just the fourth known in the Superior Province of Ontario, with others documented in the Separation Rapids pegmatite group, the Dryden pegmatite field and the Pakeagama Lake pegmatite group (Breaks, Selway and Tindle 2005).

Tantalum-Niobium Oxide Minerals in the North Aubry Pegmatite

In the North Aubry pegmatite, manganocolumbite and manganotantalite comprise the most abundant Ta-Nb oxide phases formed during magmatic crystallization and follow a trend similar to that defined for complex-type, spodumene-subtype rare-element pegmatites (Figure 6). Increase in evolution of the pegmatite-forming melt, as indicated by increasing ratios of Mn/Mn+Fe and Ta/Ta+Nb, led to a steep rise in average Ta_2O_5 contents of these minerals in a progression from the outer sodic aplite zone into the inner core zone (Table 3).

The corona zone (9) and inner core zone (10) contain amongst the most evolved manganotantalite compositions investigated by the authors from any lithium-rich pegmatite in Ontario. These zones achieve extreme, near end-member manganese and tantalum contents.

Interaction between the pegmatite-forming melt and reactive mafic metavolcanic host rocks is a consequence of the emplacement of a fluid-rich, pegmatite-forming melt. However, the assessment of

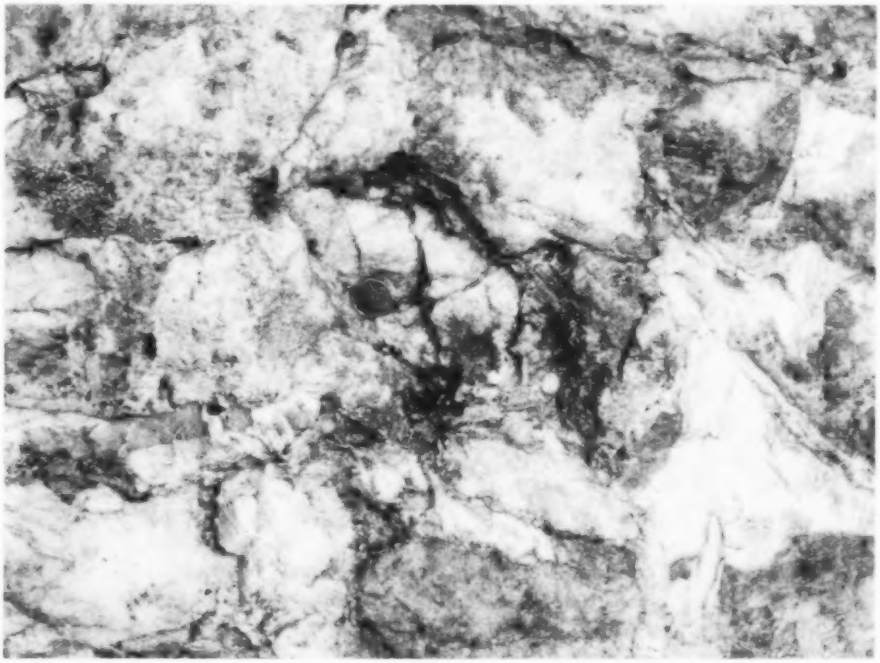

Photo 11. Pollucite, relatively unaltered as marked by coin, situated in the centre of inner core zone, Trench NA-5.

Table 3. Average Ta_2O_5 contents in columbite-tantalite from internal zones of the North Aubry pegmatite.

Internal pegmatite zone	**Mean value of Ta_2O_5 (weight %)**
Outer sodic aplite (1)	44
Muscovite-rich pods (4)	51
Potassium feldspar zone (6)	50
Albite-spodumene zone (8)	51
Potassium feldspar-spodumene zone (7)	54
Corona zone (9)	56
Inner core zone (10)	81

exomorphic processes associated with emplacement and solidification of lithium-rich, rare-element pegmatites is a complex issue as indicated elsewhere by Morgan and London (1987). At the Tanco pegmatite, these workers deciphered 3 episodes of metasomatic alteration in the mafic metavolcanic and gabbroic host rocks:

a) boron ±lithium alteration

b) potassium-rubidium-cesium-fluorine±lithium alteration

c) propylitic alteration with influx of lithium and CO_2

Calcium, iron, sodium and magnesium were introduced into the melt stage of the North Aubry pegmatite, whereas egress of K_2O, H_2O, lithium, rubidium and cesium, along with fluorine and minor boron, led to metasomatic mineral changes in the host rocks. This element exchange is particularly evident in the field by the distinctive, friable, essentially monomineralic "biotite"-rich selvages along the pegmatite contacts (*see* "Petrochemistry of the North Aubry Pegmatite"). The introduction of iron may have contributed to the formation of iron-rich, patchy zoned Ta-Nb phases such as ferrocolumbite, ferrotantalite and iron-rich manganotantalite and manganocolumbite and rare ferrotapiolite. Manganocolumbite and manganotantalite also exhibit oscillatory zoning developed during magmatic crystallization.

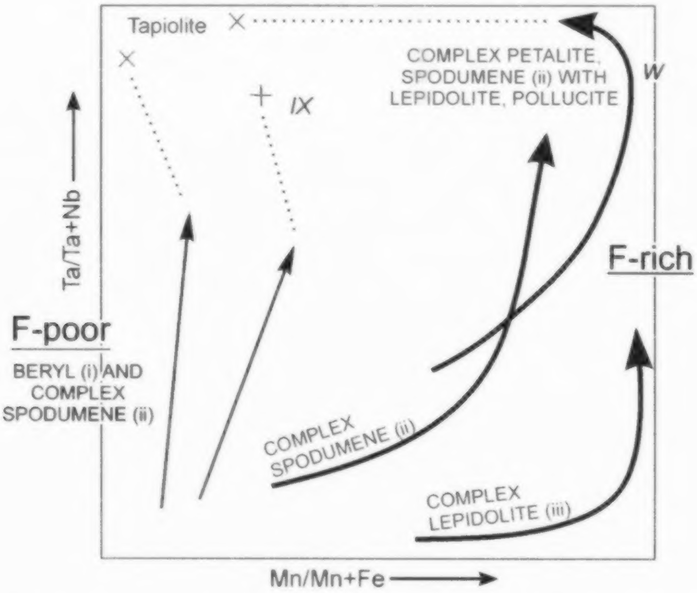
Tapiolite
COMPLEX PETALITE, SPODUMENE (ii) WITH LEPIDOLITE, POLLUCITE
W
IX
Ta/Ta+Nb
F-rich
F-poor
BERYL (i) AND COMPLEX SPODUMENE (ii)
COMPLEX SPODUMENE (ii)
COMPLEX LEPIDOLITE (iii)
Mn/Mn+Fe

Figure 6. General fractionation trends of columbite-group minerals in the columbite-tantalite quadrilateral diagram (atomic ratios) for various rare-element pegmatite types and subtypes (*after* Černý 1989). Abbreviations: IX, ixiolite; W, wodginite.

Microlite is typically distributed near the contact between the pegmatite and the host rock as a replacement of manganotantalite and ferrotapiolite. Uranium-bearing microlite has actually been documented within the biotite-rich selvages and is supportive evidence of the transfer of uranium from the pegmatite-forming melt. The uranium most likely concentrated through fractionation of the pegmatite-forming melt and not from contamination via the mafic metavolcanic host rocks. Such bulk rock compositions typically have very low radioelement contents relative to the average upper continental crust (Taylor and McLennan 1985) and is corroborated by very low uranium concentrations found in mafic metavolcanic rocks found within 4 m of the pegmatite contact in Trench NA-5 (0.05 to 0.28 ppm: *see* Tindle, Selway and Breaks 2006 (MRD 210), Table 4).

It is also logical to infer that some calcium originated through exchange with the adjacent host rocks as calc-silicate assemblages (garnet, diopside and calcite and epidote) are common in these rocks, especially near Trench NA-5 (Photos 12a and 12b). Furthermore, several biotite-rich metasomatic selvages reveal drastic decrease in CaO relative to mafic metavolcanic compositions further away from the contact (*see* "Petrochemistry of the North Aubry Pegmatite").

Iron has also been introduced at a later stage in the evolution of the North Aubry pegmatite. Post-solidification late brittle shearing and fractures guided fluids of possible hydrothermal origin. Textural evidence is provided by spodumene crystals that have been variably and commonly intensely altered in vicinity of such structures as at Trench NA-1W (Photos 13a and 13b). Here, spodumene has been replaced by an aphanitic, dark green and red, aggregate composed of secondary minerals. Some crystals reveal that the dark green black secondary minerals are overprinted by hematite-rich masses. Adjacent potassium feldspars have a red colouration due to concentration of hematite along fractures that transect the mineral.

A series of quadrilateral plots (Figures 7a to 7f) depict compositional variation of the columbite-group minerals in various internal zones of this pegmatite. All of the pegmatite zones, except for quartz-rich pods (zone 5), contain oxide minerals with compositions of manganocolumbite to manganotantalite within a magmatic trend that is characteristic of complex-type, spodumene-subtype pegmatites as generalized by Černý (1989) and depicted in Figure 6. The data array for this magmatic trend extends into extreme end-member manganotantalite compositions that lie above the trend for spodumene-subtype pegmatites of Černý (1989).

OXIDES FORMED BY PRIMARY MAGMATIC CRYSTALLIZATION AND CONTAMINATION BY HOST ROCKS

The Ta-Nb oxide minerals in the North Aubry pegmatite (*see* Figure 5) can be divided into 2 groups: magmatic group (manganocolumbite to manganotantalite) and a contamination group marked by iron-enrichment (ferrocolumbite, ferrotantalite, iron-rich manganocolumbite, iron-rich manganotantalite, ferrotapiolite and microlite).

The 2 outer pegmatite units (zones 1 and 2) are interpreted as those most affected by metasomatic interaction between pegmatite-forming melt and/or fluids and the mafic metavolcanic host rocks. The Ta-Nb oxide minerals of the contamination group consist of those enriched in iron (ferrocolumbite and ferrotapiolite) and/or calcium (iron-rich microlite).

The remaining units (zones 3 to 10), which are more distal relative to the host rock-pegmatite contact, contain minerals that more likely represent products of primary magmatic crystallization. Textural evidence indicates that both primary and secondary microlite occur in the outer sodic aplite zone (*see* below). Primary microlite, conceivably formed via calcium-fluorine-complexing subsequent to apatite crystallization, would have depleted the pegmatite melt in phosphorus, thus causing the remaining calcium (and uranium) to be incorporated into microlite.

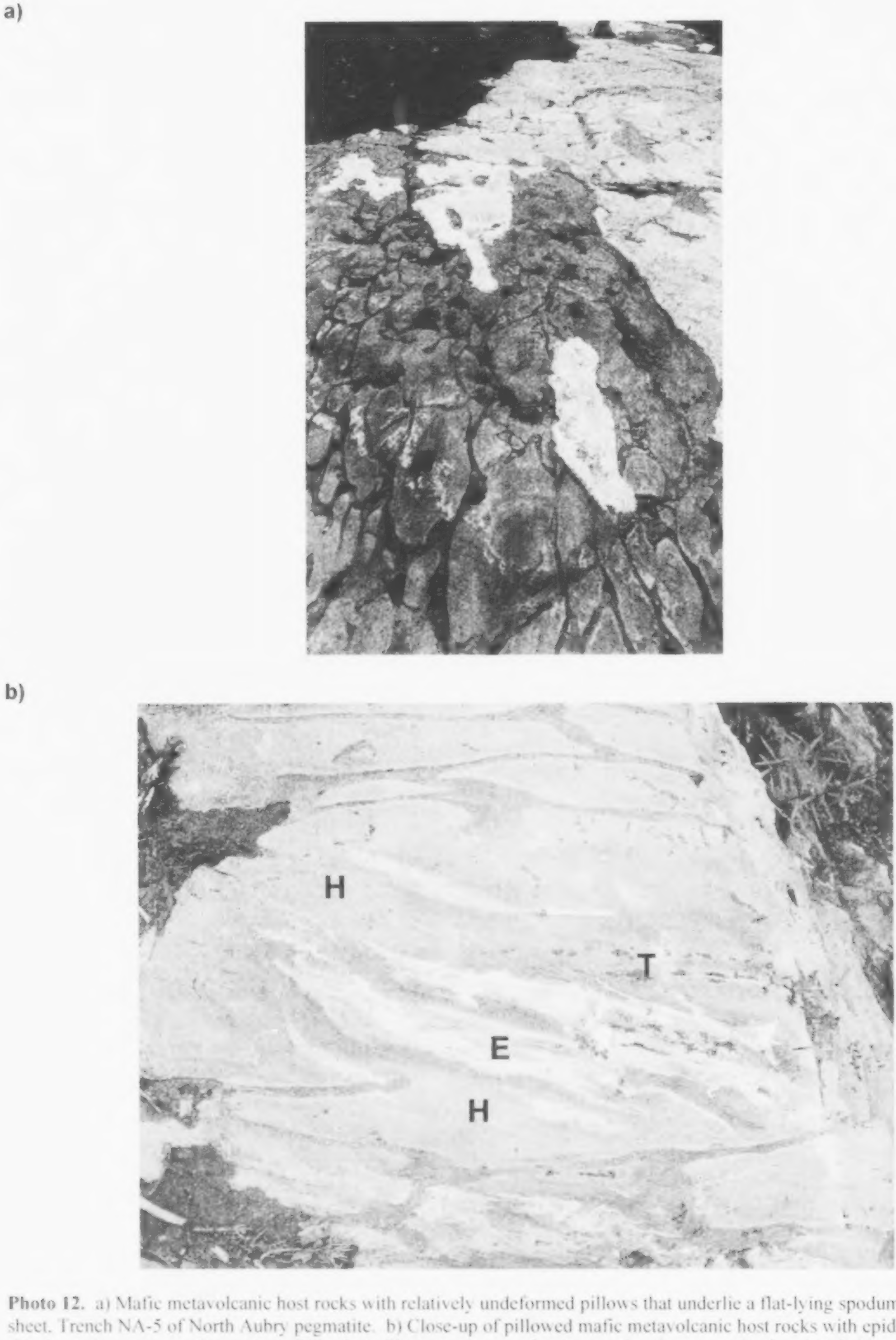

Photo 12. a) Mafic metavolcanic host rocks with relatively undeformed pillows that underlie a flat-lying spodumene pegmatite sheet. Trench NA-5 of North Aubry pegmatite. b) Close-up of pillowed mafic metavolcanic host rocks with epidote-rich masses (E) situated near pegmatite contact. This photo illustrates stages of metasomatism by pegmatite-forming fluids: H = blue areas of pervasive holmquistite due to lithium metasomatism overprinted by dark porphyroblasts of tourmaline (T) that relates to a later influx of boron-bearing fluids from the pegmatite.

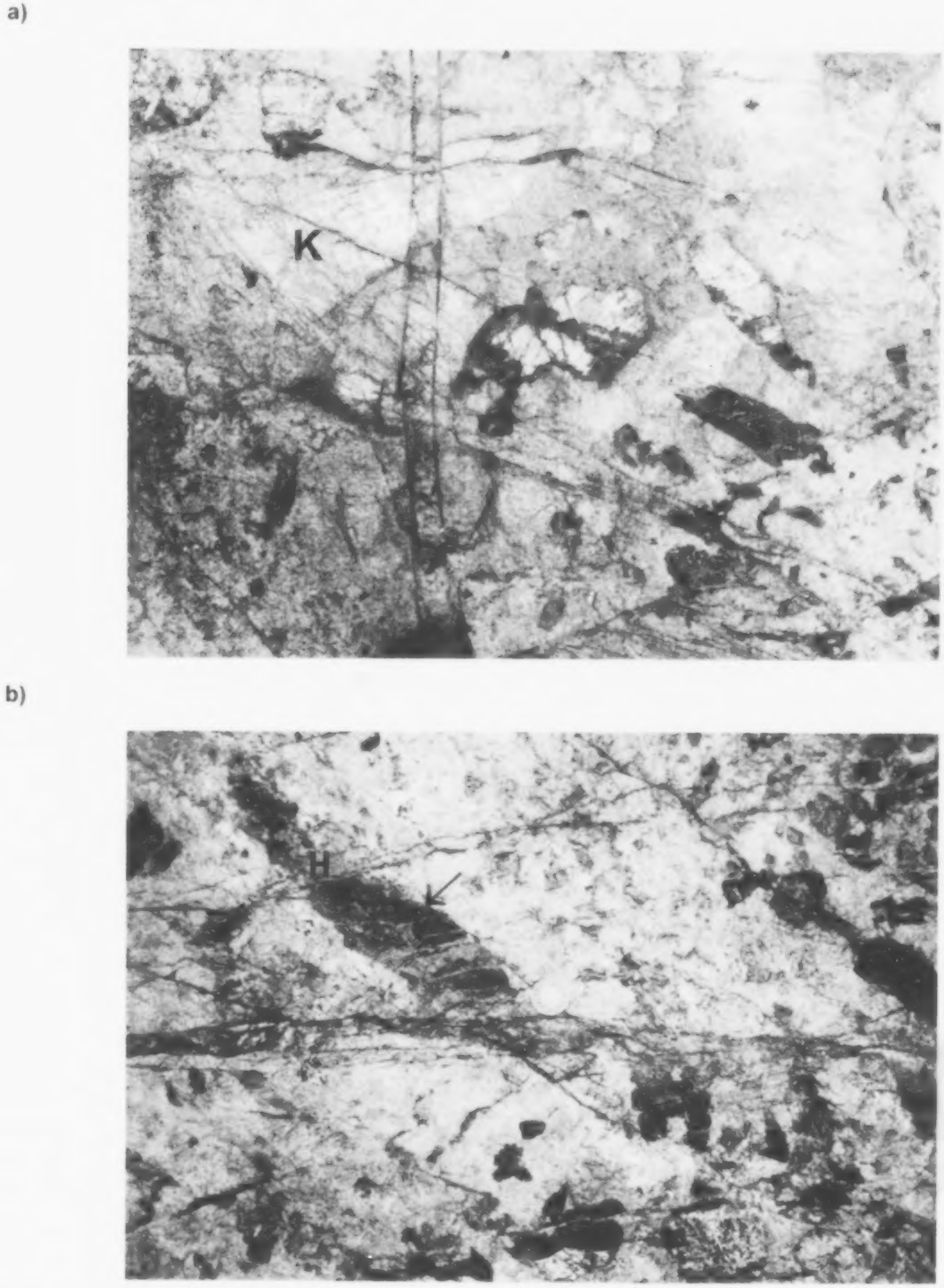

Photo 13. a) Former spodumene, now markedly altered to aphanitic aggregates of green black secondary phases. Numerous fractures transect the spodumene and adjacent potassium feldspar (K) and the latter has a strong red hue due to hematite introduced along these structures. b) Completely altered spodumene (arrow) that is segmented by sinustral offset along brittle shear marked by coin. Two stages of secondary minerals are evident as early dark green black masses overprinted by hematite-dominant masses and veins (H).

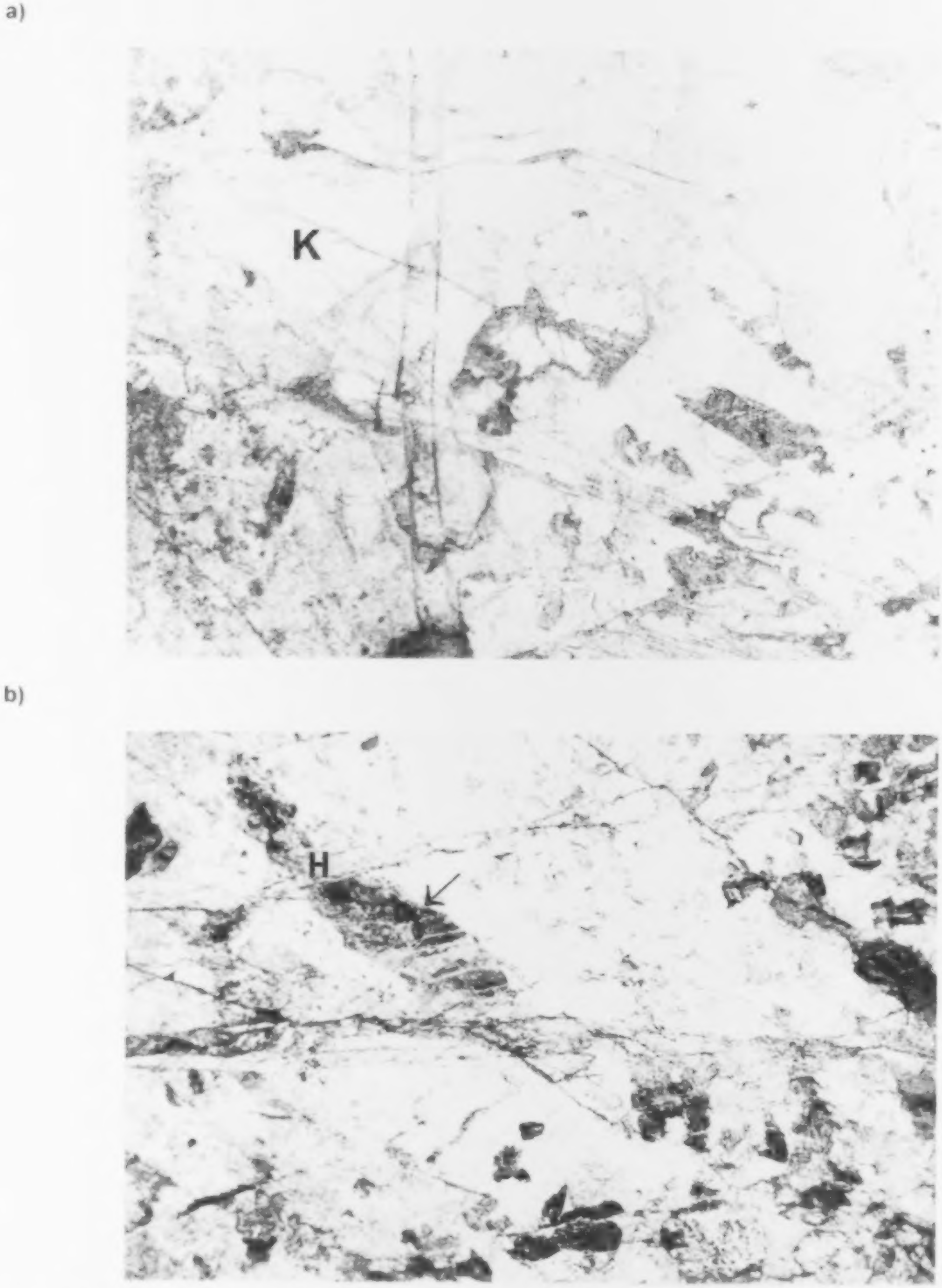

Photo 13. a) Former spodumene, now markedly altered to aphanitic aggregates of green black secondary phases. Numerous fractures transect the spodumene and adjacent potassium feldspar (K) and the latter has a strong red hue due to hematite introduced along these structures. b) Completely altered spodumene (arrow) that is segmented by sinistral offset along brittle shear marked by coin. Two stages of secondary minerals are evident as early dark green black masses overprinted by hematite-dominant masses and veins (H).

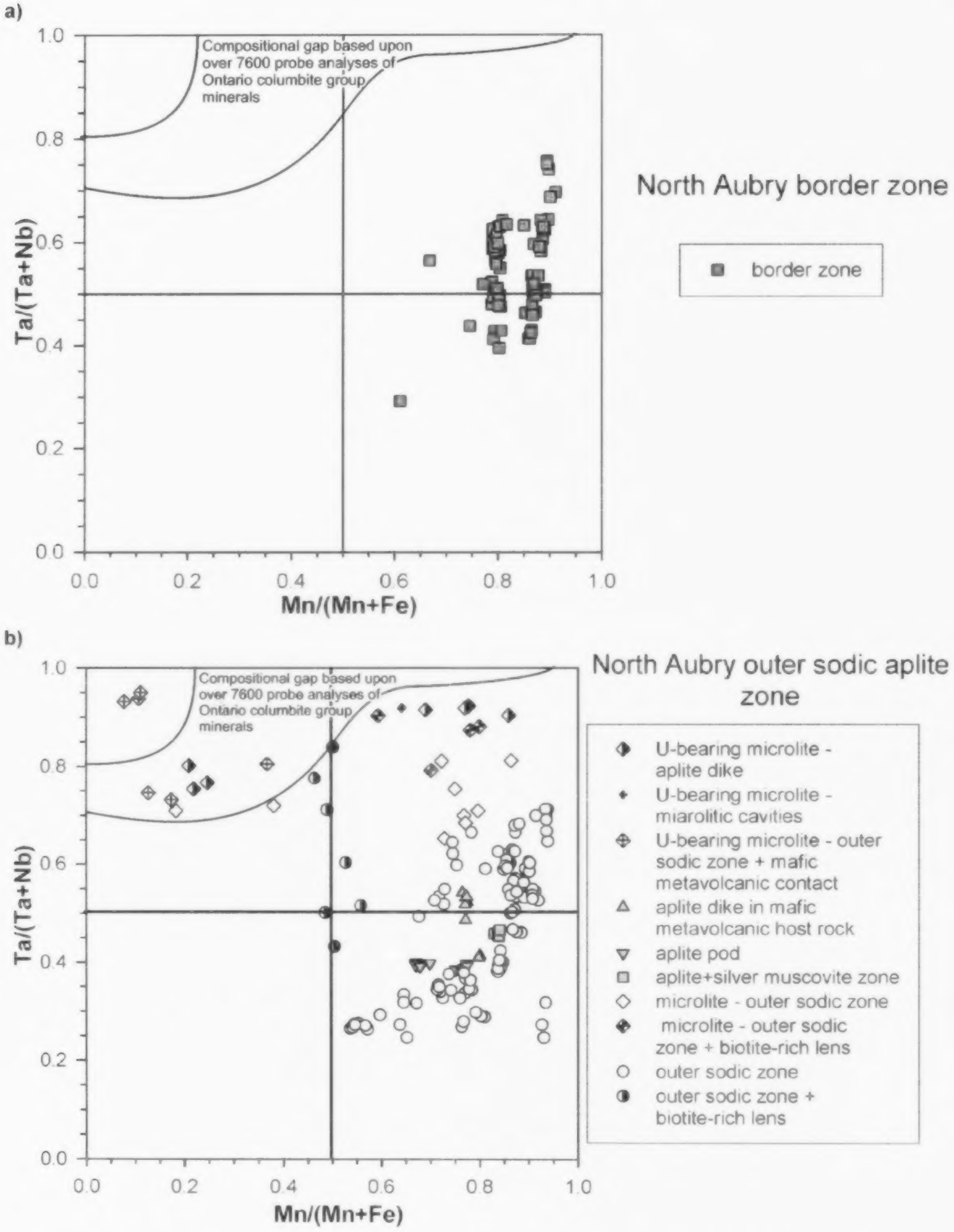

Figure 7. Columbite-tantalite quadrilateral plots (atomic ratios) for various internal zones of the North Aubry pegmatite: a) border zone, and b) outer sodic aplite zone.

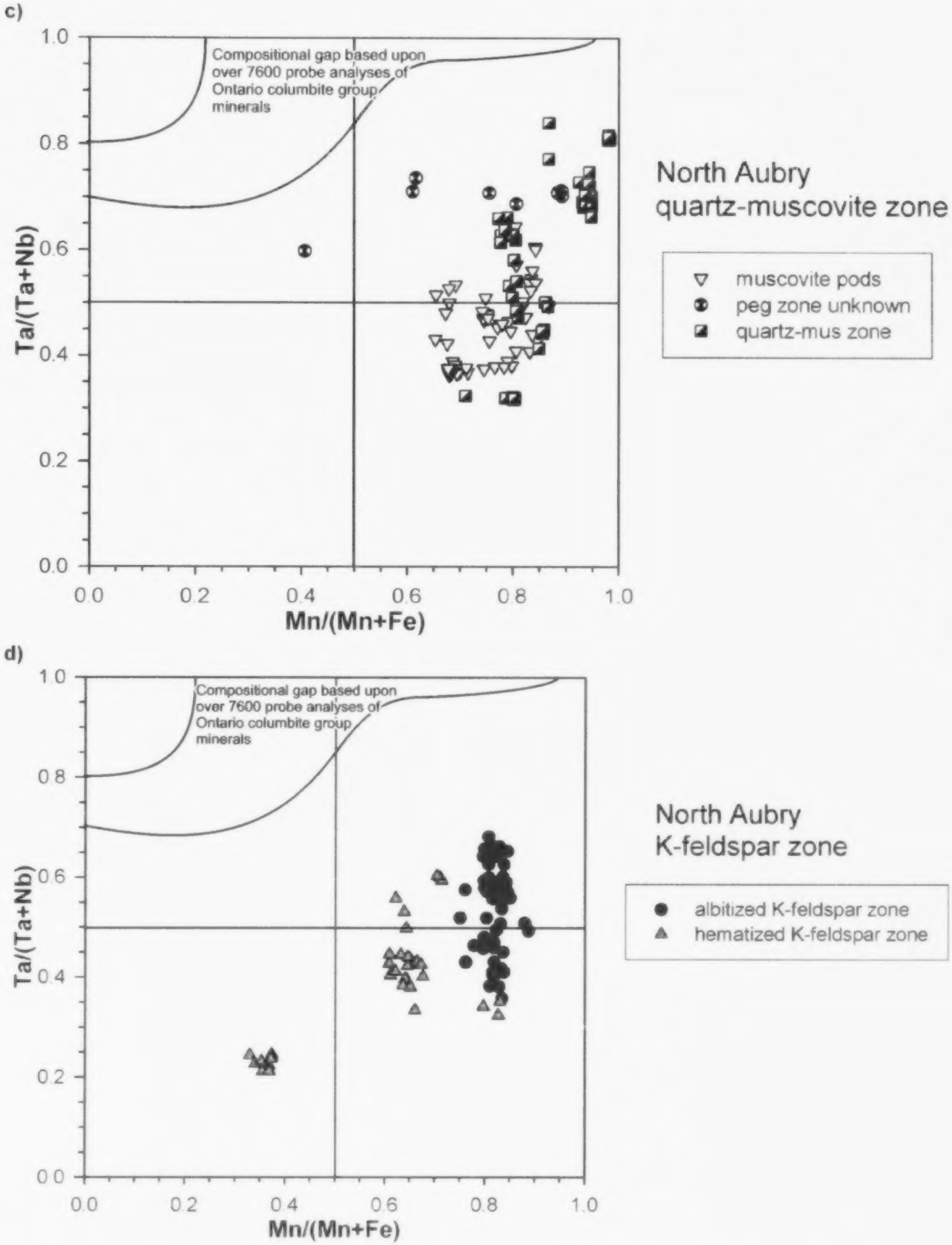

Figure 7, continued. Columbite-tantalite quadrilateral plots (atomic ratios) for various internal zones of the North Aubry pegmatite: c) quartz-muscovite zone, and d) potassium feldspar zone.

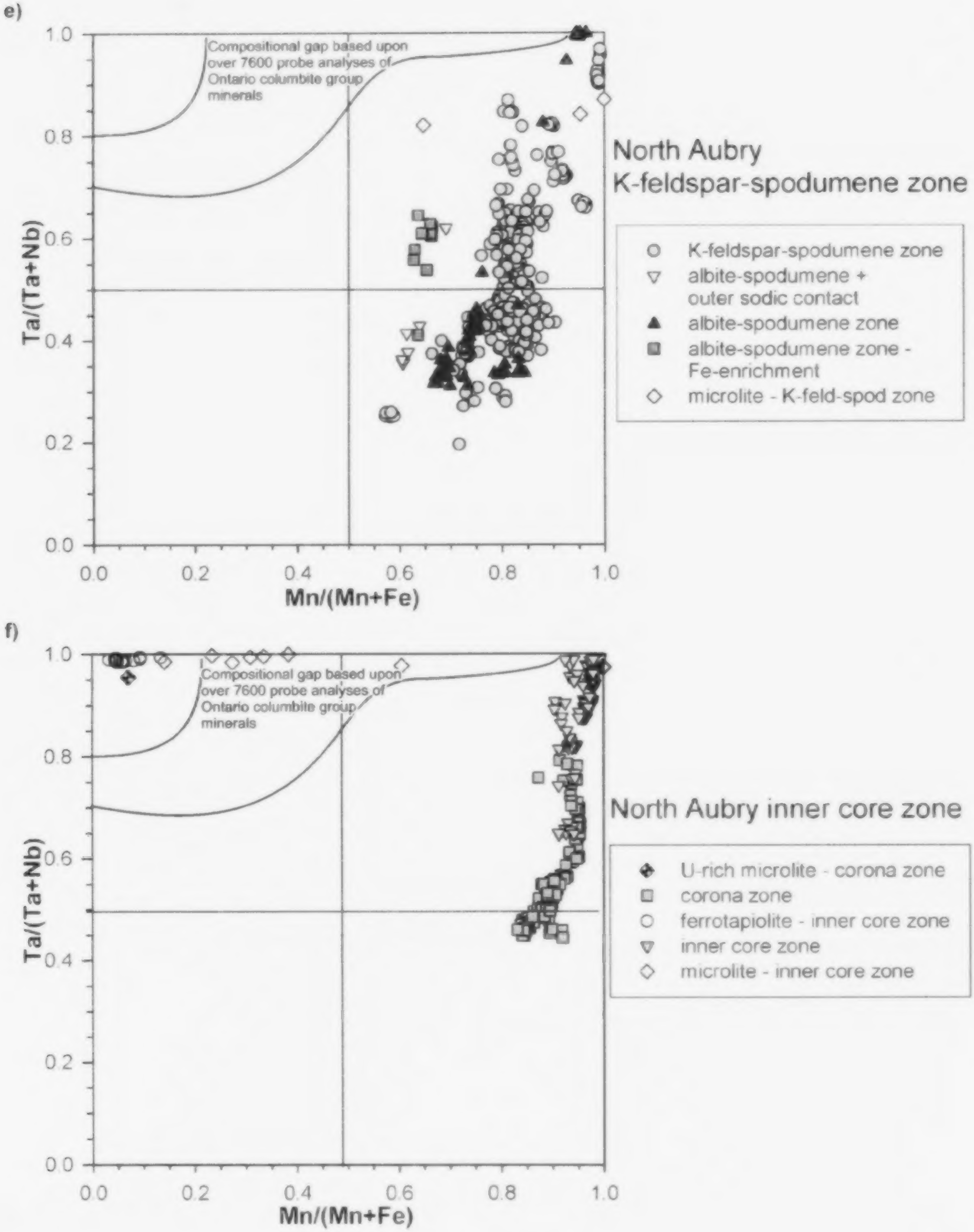

Figure 7, continued. Columbite-tantalite quadrilateral plots (atomic ratios) for various internal zones of the North Aubry pegmatite: e) potassium feldspar-spodumene zone, and f) corona zone and inner core zone. Compositional gap between ferrotapiolite and ferrotantalite is based upon 7600 compositions of columbite-tantalite from Ontario. Microlite compositions may plot within this compositional space.

Evidence of iron enrichment in the pegmatite-forming melts that form the outer zones of the pegmatite is supported by the presence of garnet and tourmaline. However, at an isolated exposure at Trench NA-1W (Dimmell and Morgan 2006, p.50), iron enrichment in the form of hematization of potassium feldspar and spodumene is more likely due to fluids introduced along brittle shears that postdate the pegmatite (*see* Photos 13a and 13b).

Border Zone (1)

The oxide minerals in the border zone follow the magmatic trend from manganocolumbite to manganotantalite (mean = 54.19 weight % Ta_2O_5; range = 42.13 to 69.49 weight % Ta_2O_5). The grains reveal strong oscillatory zonation (Photo 14) with 2 distinct compositions based on Mn content: Mn/(Mn+Fe) 0.77 to 0.82 and 0.85 to 0.91 (*see* Figure 7a).

Outer Sodic Aplite Zone (2)

The oxide minerals in the outer sodic zone and derivative aplite dikes follow the magmatic trend from manganocolumbite to manganotantalite (*see* Figure 7b) with a mean of 49.34 weight % Ta_2O_5 and a range of 28.48 to 70.54 weight % Ta_2O_5. The oxide grains are unzoned (Photo 15), patchy zoned or oscillatory zoned and are commonly replaced by microlite (57.74 to 71.23 weight % Ta_2O_5).

Microlite replacement of manganocolumbite and manganotantalite (*see* Photo 15) typically occurs proximal to the mafic metavolcanic host rocks. This observation infers that the calcium essential for the formation of microlite may have been scavenged from the host rocks under the agency of pegmatite-derived fluids. Secondary microlite, as exemplified by 01-JBS-38-07, is iron rich (Mn/(Mn+Fe) = 0.07 to 0.37) with elevated UO_2 (0.57 to 5.69 weight %) and Ta_2O_5 (56.7 to 66.7 weight %).

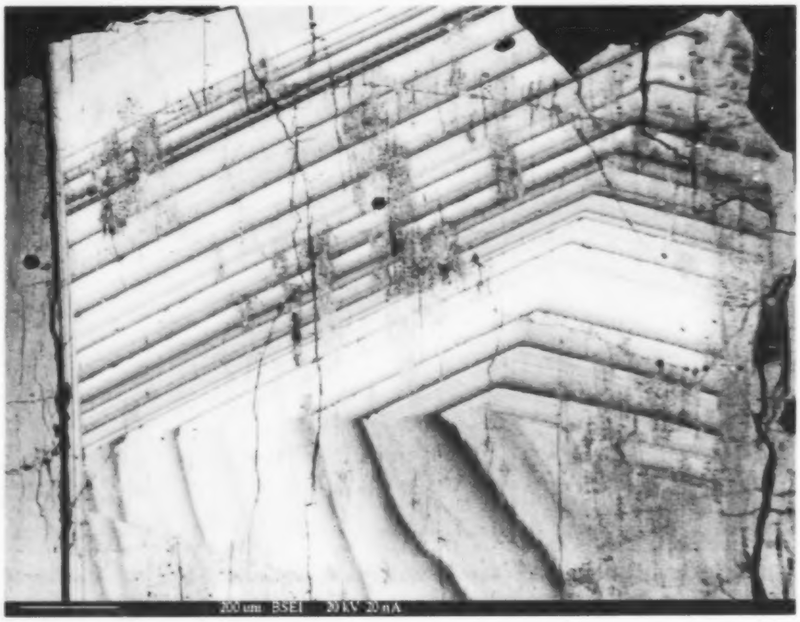

Photo 14. Spectacular oscillatory zoning in manganotantalite from the border zone, eastern end of Trench NA-2 (locality 01-AGT-10-14).

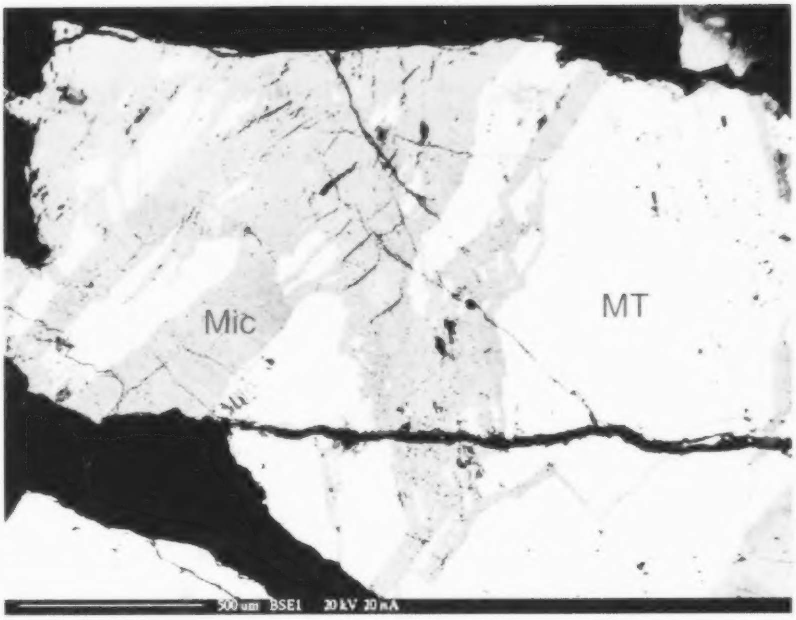

Photo 15. Unzoned manganotantalite (MT) replaced by microlite (Mic) from the outer sodic aplite zone. Trench NA-5 (locality 01-AG1-10-23).

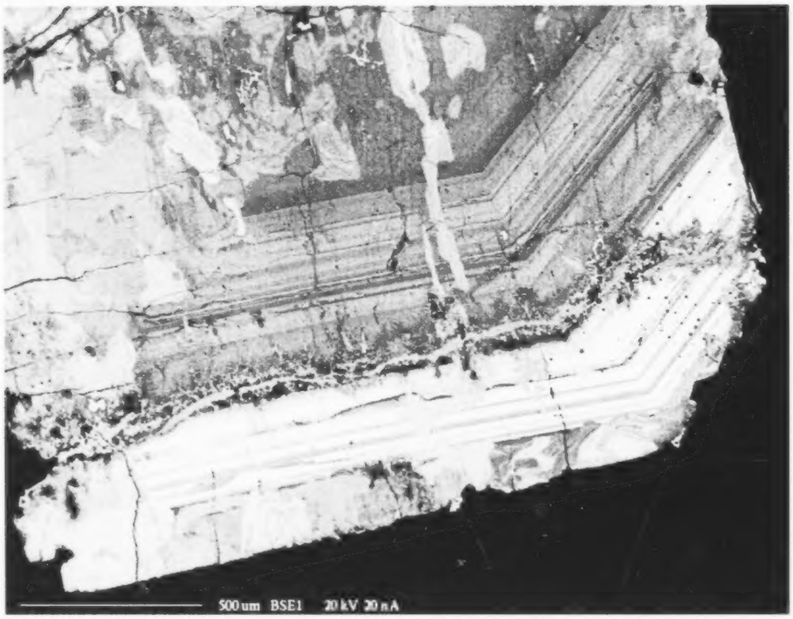

Photo 16. Strong oscillatory zoning in oxide crystal from the quartz-muscovite zone. Trench NA-3 (locality 02-JBS-45-01). Grain varies from manganocolumbite (core) to manganotantalite near the crystal margin. Irregular masses and veins of later, patchy zoned manganocolumbite cuts across the zoning.

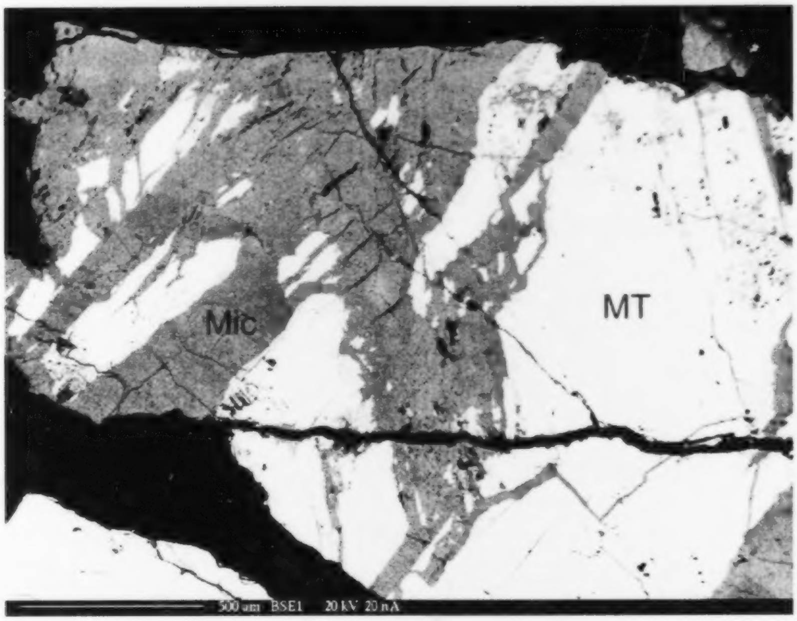

Photo 15. Unzoned manganotantalite (MT) replaced by microlite (Mic) from the outer sodic aplite zone. Trench NA-5 (locality 01-AGT-10-23).

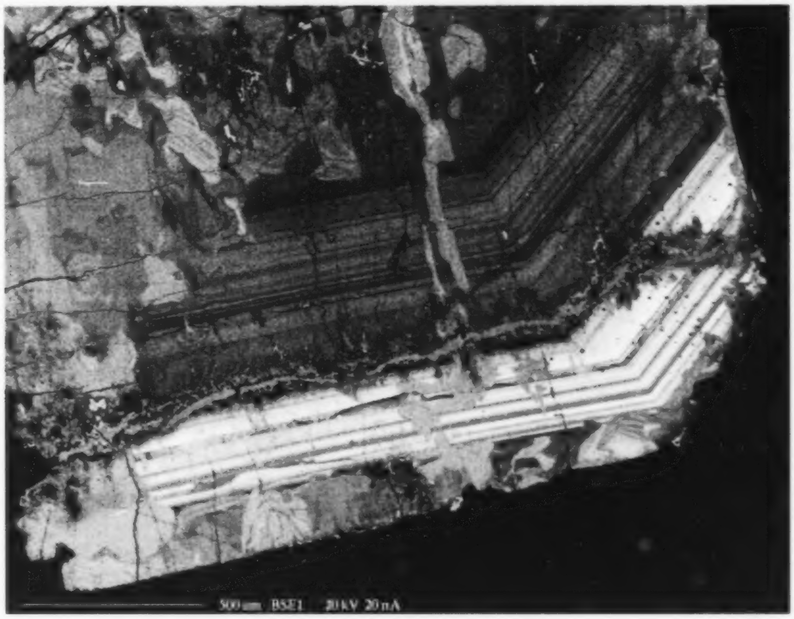

Photo 16. Strong oscillatory zoning in oxide crystal from the quartz-muscovite zone. Trench NA-3 (locality 02-JBS-45-01). Grain varies from manganocolumbite (core) to manganotantalite near the crystal margin. Irregular masses and veins of later, patchy zoned manganocolumbite cuts across the zoning.

Manganotantalite, situated 0.5 m from the contact with the host rock at 02-JBS-41-32, has a patchy core and an oscillatory zoned rim. The oscillatory zoning likely developed during magmatic crystallization, whereas the patchy zoning could represent crystallization under conditions of relatively high iron induced via influx from the host rocks to the pegmatite-forming melt.

A further example illustrates iron-enrichment in Ta-Nb oxide minerals at the contact between the outer sodic aplite zone and a highly metasomatized, biotite-rich host rock enclave. Here, ferrotantalite (02-JBS-34-01) reveals iron enrichment [Mn/(Mn+Fe) = 0.5] that plots distinct from the magmatic trend (*see* Figure 7b).

Primary microlite occurs in miarolitic cavities close to the contact with the mafic metavolcanic host rock (01-AGT-10-09) where tiny uranium-bearing microlite inclusions (2.15 to 3.47 weight % UO_2) are distributed in quartz. Secondary microlite is exemplified within a 2 m wide aplite dike at 01-AGT-10-10 that is inferred as an exocontact derivative of the outer sodic aplite zone. In this dike, a mottled grain of manganocolumbite to manganotantalite contains uranium-bearing microlite (1.42 to 3.47 weight % UO_2) distributed along fractures and in small patches throughout the grain.

Quartz-Muscovite Zone (3) and Muscovite-rich Pods (4)

The Ta-Nb oxide minerals in the quartz-muscovite zone and muscovite-rich pods follow the magmatic trend from manganocolumbite to manganotantalite (*see* Figure 7c). In the quartz-muscovite zone, these minerals exhibit both oscillatory and replacement stage patchy zoning (Photo 16) with an average of 58.08 weight % Ta_2O_5, a wide range of 35.16 to 76.75 weight % Ta_2O_5 and Mn/(Mn+Fe) = 0.71 to 0.98. The oxides with oscillatory zoning tend to be more tantalum and manganese rich than the patchy zoned oxides. For example, 02-FWB-35 contains oscillatory zoned manganotantalite with 64.62 to 71.49 weight % Ta_2O_5 and a Mn/(Mn+Fe) = 0.87 to 0.95.

The oxides in the muscovite-rich pods are mostly patchy zoned, manganocolumbite with minor manganotantalite with an average of 48.93 weight % Ta_2O_5, a range of 39.34 to 66.06 weight % Ta_2O_5 and an average Mn/(Mn+Fe) = 0.72.

Potassium Feldspar Zone (6)

The Ta-Nb oxide minerals (manganocolumbite to manganotantalite) from the potassium feldspar zone (*see* Figure 7d) are can be divided into 2 groups based on Mn/(Mn+Fe) ratios and associated feldspar textures:

a) albitized potassium feldspar with an average Mn/(Mn+Fe) = 0.89 and a range of 39.01 to 66.62 weight % Ta_2O_5

b) hematized potassium feldspar with an average of Mn/(Mn+Fe) = 0.67 and a range of 35.97 to 58.77 weight % Ta_2O_5

The oxide minerals from the hematized parts of the potassium feldspar zone are more iron enriched than those from the albitized potassium feldspar zone as illustrated by sample 02-JBS-44-09. Here, the least evolved Ta-Nb oxide compositions in the entire North Aubry pegmatite are found as oscillatory zoned ferrocolumbite with an average of 25.73 weight % Ta_2O_5 and a Mn/(Mn+Fe) = 0.36. The compositions from this locality plot as a cluster in Figure 7d in the ferrocolumbite field that is isolated from the main magmatic trend. Such oxide minerals, which exhibit oscillatory zoning textures, most likely crystallized from a pegmatite-forming melt with relatively high iron levels.

Albite-Spodumene Zone (7)

The Ta-Nb oxide minerals in the albite-spodumene zone (*see* Figure 7e) comprise manganocolumbite to manganotantalite [mean Ta_2O_5 = 43.59 weight %; range Mn/(Mn+Fe) = 0.63 to 0.84]. Significant tantalum enrichment is found in 02-JBS-36-02 from Trench NA-6 where manganotantalite contains 76.04 to 86.93 weight % Ta_2O_5 coupled with an extremely high Mn/(Mn+Fe) = 0.88 to 0.96.

Relatively early formed Ta-Nb oxides occur as inclusions in spodumene and quartz within the albite-spodumene zone. In 02-JBS-34-12 from Trench NA-4, a 4-5 mm, oscillatory zoned grain of manganocolumbite and manganotantalite (37.3 to 60.6 weight % Ta_2O_5) contains smaller patchy grains of manganocolumbite.

Potassium Feldspar-Spodumene Zone (8)

The Ta-Nb oxide minerals in this zone (*see* Figure 7e) comprise oscillatory and patchy zoned manganocolumbite to manganotantalite (average Ta_2O_5 = 54.22 weight %; range = 23.12 to 84.72 weight %) with a high manganese content as reflected by the mean Mn/(Mn+Fe) = 0.83. The most evolved oxide composition from this pegmatite zone is a distinct red-brown manganotantalite in 02-FWB-36 from Trench NA-5-6 with 74.05 to 84.72 weight % Ta_2O_5.

Some of the oscillatory zoned grains have manganocolumbite cores and manganotantalite rims marked by an increase in manganese and tantalum from core to rim. These grains are likely primary magmatic in origin, and follow the magmatic trend of Černý (1989) for complex-type pegmatites. A good example is found in 02-JBS-41-17 (Trench NA-6) in which grains with a manganocolumbite core (46.02 to 50.77 weight % Ta_2O_5 and Mn/(Mn+Fe) = 0.73 to 0.80) are successively enveloped by a manganotantalite zone (51.90 to 63.46 weight % Ta_2O_5 and Mn/(Mn+Fe) = 0.81 to 0.85), and a thin manganocolumbite rim (51.67 weight % Ta_2O_5) and Mn/(Mn+Fe) = 0.50.

The most primitive oxide mineral composition (02-JBS-44-03 in Trench NA-2-3) from this pegmatite zone comprises a manganocolumbite inclusion in potassium feldspar (mean Ta_2O_5 = 28.92 weight % and Mn/(Mn+Fe) = 0.58). Green beryl, situated near the host rock in 02-JBS-32-11D from Trench SA-5, also contains inclusions of zoned microlite (67.56 to 69.93 weight % Ta_2O_5) and patchy zoned manganocolumbite (31.97 to 42.19 weight % Ta_2O_5). The enrichment in iron in oxide phases, relative to the main magmatic trend, may relate to early crystallization and an inability of grains in this particular niche to re-equilibrate with the pegmatite-forming melt due to the enclosure by potassium feldspar.

Corona Zone (9)

The Ta-Nb oxide minerals from the corona zone and inner core zone (*see* Figure 7f) are more evolved and manganese rich relative to other internal zones of the North Aubry pegmatite. The oxide minerals from this zone are mostly manganocolumbite to manganotantalite with a range of 46.87 to 73.49 weight % Ta_2O_5 and an average Mn/(Mn+Fe) = 0.90.

Most of the oxide mineral grains are lath-shaped and unzoned. A few manganotantalite grains are zoned with relatively tantalum-poor cores and tantalum-rich rims. For example, 02-JBS-37-03A from Trench NA-5, contains manganotantalite with 56.40 to 66.75 weight % Ta_2O_5 in the core and 70.48 to 72.12 weight % Ta_2O_5 in the rim in the matrix of purple muscovite aplite. The corona zone contains one grain of altered, uranium-rich microlite (02-JBS-42-08B: UO_2 = 10.08 weight % and Ta_2O_5) that is mantled by magnetite in the purple muscovite aplite matrix.

Inner Core Zone (10)

The oxide minerals in the inner core zone (*see* Figure 7f) are the most tantalum rich in the North Aubry pegmatite and comprise manganotantalite, ferrotapiolite, microlite and rare tantalian rutile. Unzoned manganotantalite contains 62.86 to 85.62 weight % Ta_2O_5 and an average of Mn/(Mn+Fe) = 0.92. The ferrotapiolite has a range in composition from 83.92 to 85.49 weight % Ta_2O_5 and tends to be deep red in thin section.

Primary manganotantalite (83.85 to 84.83 weight % Ta_2O_5) with ferrotapiolite (83.92 to 84.80 weight% Ta_2O_5) occurs in 01-AGT-10-23 from Trench NA-5, and both phases are replaced by microlite (77.90 to 80.97 weight % Ta_2O_5). Tantalian rutile with (1.50 to 8.22 weight % Ta_2O_5 and 1.71 to 3.12 weight % SnO_2) is associated with spessartine inclusions hosted in coarse spodumene (01-AGT-10-11, Trench NA-5).

Other Minerals in the North Aubry Pegmatite and Adjacent Host Rocks

MAFIC METAVOLCANIC HOST ROCKS

The mafic metavolcanic host rocks of the North Aubry pegmatite have been intensely metasomatized adjacent to the contacts as indicated by mineralogical and bulk chemical changes (*see* "Petrochemistry of the North Aubry Pegmatite"). The host rocks within a few metres of the pegmatite contact generally exhibit a selvage composed of abundant, anhedral biotite (up to 95 volume %), and local tourmaline needles and acicular holmquistite. Minor anhedral calcite, epidote, quartz, chlorite and pyrite cubes may also be present. Tourmaline and holmquistite form a lineation in the rocks as at Trench NA-5.

The "biotite" in the potassium-rich, metasomatized mafic metavolcanic rocks is actually siderophyllite-zinnwaldite (Figure 8) that is rich in MgO (4.4 to 15.6 weight %), Cs_2O (0.18 to 3.92 weight %) and Rb_2O (0.85 to 2.43 weight %). This is the most cesium-rich mica associated with the North Aubry pegmatite.

The siderophyllite-zinnwaldite is commonly zoned with relatively cesium-poor cores and cesium-rich rims as exemplified by 02-JBS-38-10 from Trench NA-5 (core: 3.3 weight %; rim: 0.39 weight %). The cesium-rich rims are possibly due to an interaction of previously formed siderophyllite-zinnwaldite with elevated cesium levels developed in a late-stage residual melt or fluid. Such textures have been documented in muscovite from several other lithium-rich pegmatites in the Superior Province of Ontario such as at Pakeagama Lake (Tindle, Breaks and Selway 2002; Smith 2001; Smith et al. 2005) and at Marko's pegmatite in the Separation Rapids pegmatite group (Breaks and Tindle 2002 and unpublished data of the authors).

Zinnwaldite, a lithium-, iron- and fluorine-rich mica, was documented at the contact between the host rock and the outer sodic aplite zone and it also contains elevated Cs_2O (up to 1.35 weight %) and Rb_2O (0.15 to 1.49 weight %). Fluorine levels in zinnwaldite range from 1.2 to 3.4 weight %.

Tourmaline in the host rocks mainly consists of calcium-rich dravite-schorl and calcium-rich schorl-dravite. Massive tourmaline, as exemplified by 02-JBS-30-08 from Trench NA-5-6, occurs as a fine-grained, fracture coating in the outer sodic aplite zone next to the host rock. The tourmaline is zoned with calcium-rich dravite-schorl cores and calcium-rich schorl-dravite rims that most likely represent magnesium and calcium scavenged from the host rocks under the agency of pegmatite-forming fluids.

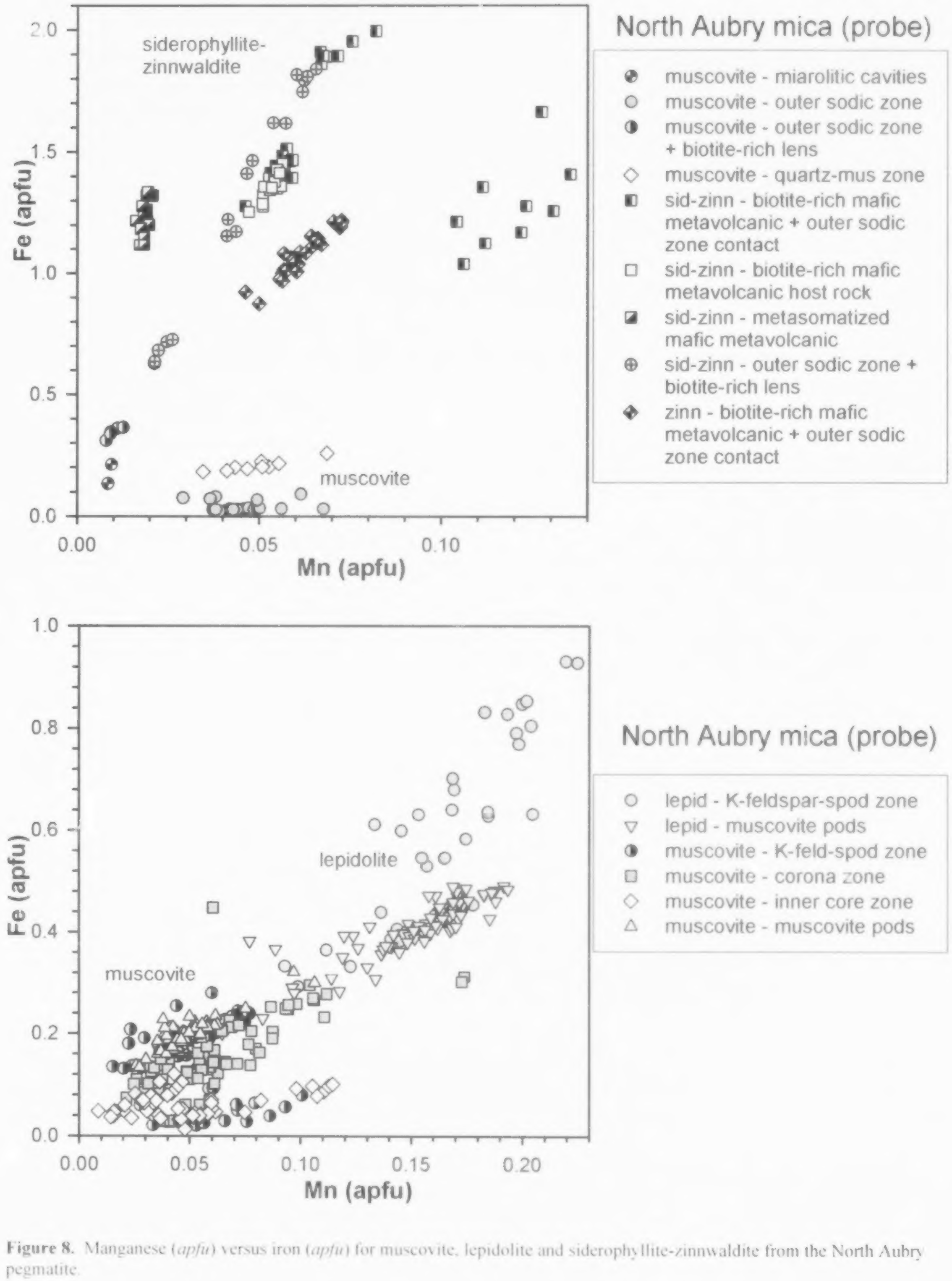

Figure 8. Manganese (*apfu*) versus iron (*apfu*) for muscovite, lepidolite and siderophyllite-zinnwaldite from the North Aubry pegmatite.

OUTER PEGMATITE ZONES AFFECTED BY CONTAMINATION

The outer pegmatite units (border zone and sodic aplite zone) were possibly the most affected by metasomatic interaction of pegmatite-forming melt and/or fluids and the mafic metavolcanic host rocks. Minerals that are deemed reflective of this process comprise cesium-rich siderophyllite-zinnwaldite, calcium-rich dravite-schorl, calcium-rich schorl-dravite (iron- and magnesium-rich tourmaline) and holmquistite (iron-, magnesium- and lithium-rich amphibole).

The minerals in the miarolitic cavities, which locally occur in the outer sodic aplite zone, provide direct evidence of a late-stage, exsolved fluid (London 1992) that contained some magnesium (tourmaline rims), calcium (microlite, fluorapatite), fluorine (tourmaline rims, microlite, fluorapatite, lepidolite rims), sodium and boron (tourmaline rims, albite, beryl) and cesium (beryl). Garnet and tourmaline, in particular, are essentially confined proximal to the pegmatite contact and are rarely found in the interior pegmatite zones.

The accessory minerals reflect a crystallization pattern in the pegmatite-forming melt that was initially had moderate manganese contents (e.g., in cores of garnet and fluorapatite). Subsequently, the pegmatite-forming melt, at least in the outermost parts, was contaminated by interaction with the host rock and iron-, magnesium- and calcium-enriched compositions crystallized (e.g., in rims of microlite, garnet and fluorapatite).

Border Zone (1)

The border zone crystallized from the pegmatite melt to form Ta-Nb oxide minerals, fluorapatite and zoned tourmaline with aluminum-rich cores (magmatic) and magnesium-rich rims (contamination from host rocks). Black tourmaline in 02-JBS-44-13 from Trench NA-2-3 consists of a 19 cm long prismatic cluster that consists of calcium-bearing magnesium-rich schorl enveloped by plagioclase, blue fluorapatite and minor biotite, muscovite and pyrite.

Outer Sodic Aplite Zone (2)

The outer sodic aplite zone essentially consists of altered feldspars and quartz with accessory garnet, fluorapatite, muscovite, tourmaline, and oxide minerals. Green muscovite in the aplite is enriched in Rb_2O (1.09 to 1.68 weight %) and Cs_2O (0.25 to 0.37 weight %). Rare molybdenite occurs close to the contact with a biotite-rich enclave.

The orange garnet (Figures 9a and 9b) is dominantly spessartine (69 to 91% spessartine, 8 to 30% almandine) with zonation marked by manganese-rich cores and iron-, magnesium- and calcium-rich rims (*see* Tindle, Selway and Breaks 2006 (MRD 210), various tables with electron microprobe data (folder "Probe Data")). For example, 02-JBS-34-01A has manganese-rich cores (86% spessartine, 13% almandine) and iron-rich rims (56 to 58% spessartine, 39 to 41% almandine). Calcium-enrichment is seen in 02-JBS-34-02 that has manganese-rich cores (62% spessartine, 34% almandine) and iron- and calcium-rich rims (47% spessartine, 37% almandine, 13% grossular).

Blue fluorapatite in the outer sodic aplite zone (Figure 10) is manganese rich (1.49 to 5.81 weight % MnO), but fluorapatite associated with tourmaline is relatively manganese poor (0.35 to 1.04 weight % MnO) and probably late stage in crystallization. Both fluorapatite compositional types are zoned with manganese-rich cores and manganese-poor and calcium-rich rims. Strong compositional zoning with MnO-rich cores (3.95 to 5.81 weight %) and rims with lower MnO (1.49 to 2.64 weight %) is exemplified by 02-JBS-31-02.

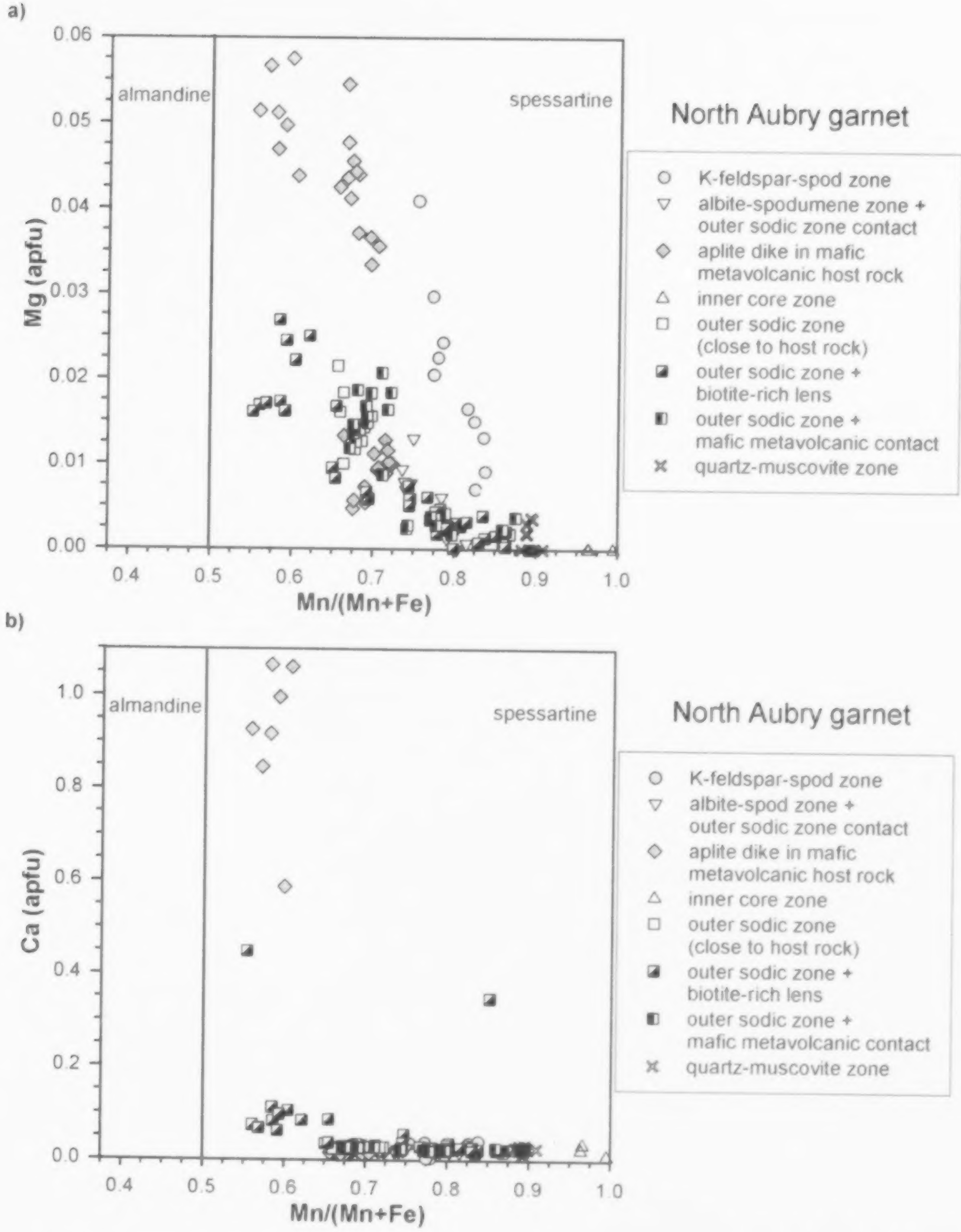

Figure 9. Garnet compositional variation from the North Aubry pegmatite: Mn/Mn+Fe versus a) magnesium (*apfu*) and b) calcium (*apfu*).

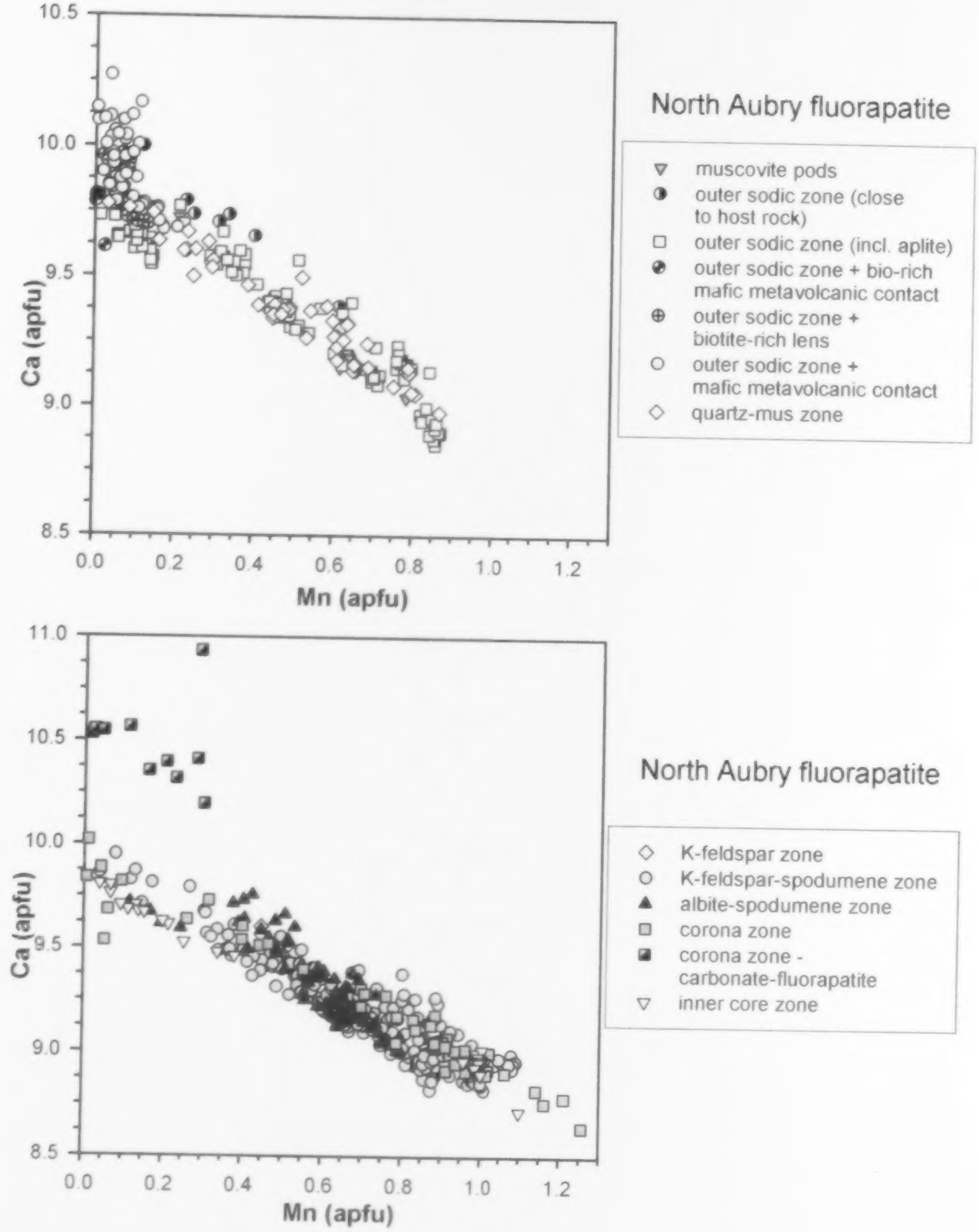

Figure 10. Fluorapatite compositional variation as manganese (*apfu*) versus calcium (*apfu*) for various internal zones of the North Aubry pegmatite.

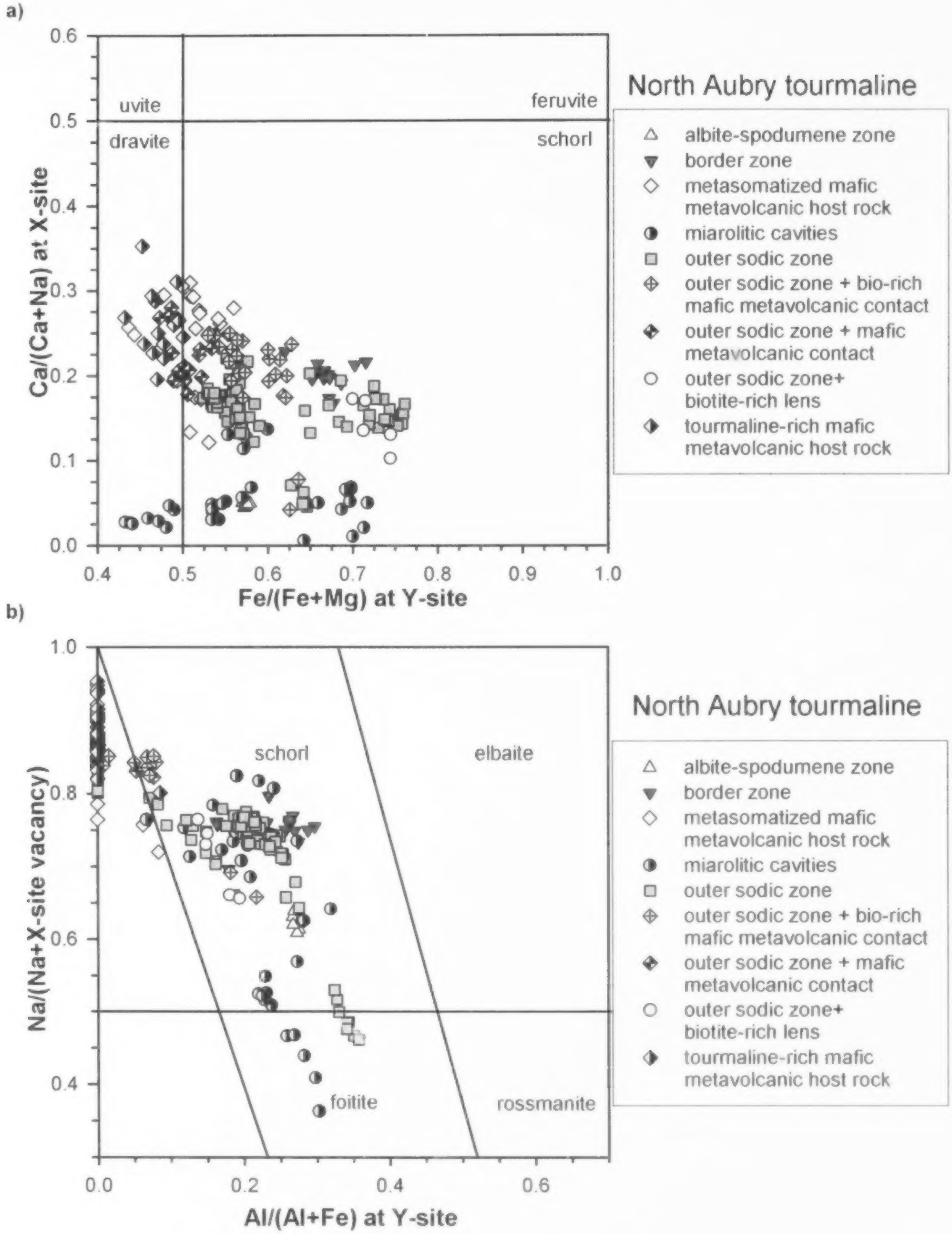

Figure 11. Tourmaline compositional variation from the North Aubry pegmatite: a) Fe/(Fe+Mg) at the Y-site versus Ca/(Ca+Na) at the X-site. b) Al/(Al+Fe) at the Y-site versus Na/(Na+X-site vacancy).

Tourmaline, bright blue in thin section, generally consists of calcium-bearing magnesium-rich schorl (Figures 11a, 11b and 11c). Radiating, zoned tourmaline from Trench NA-4, consists of magnesium-rich foitite-schorl cores (aluminum and iron rich) and calcium-bearing schorl-dravite rims (calcium and magnesium rich) in basal section and calcium-bearing schorl-dravite along prisms (Photo 17). This tourmaline is associated with yellow-green muscovite, manganese-poor fluorapatite, a large garnet crystal and 2 grains of cassiterite (0.88 to 3.44 weight % Ta_2O_5) that is the sole locality for this mineral in the Aubry pegmatite system.

Labradorite (An_{47-67}) occurs in aplite at 02-JBS-34-09D as light purple, very fine-grained, irregular-shaped aggregates (less than 1 cm across). The appearance of this mineral in the outer sodic zone provides evidence for at least local calcium-enrichment of the pegmatite-forming melt during the metasomatism of biotite-rich enclaves.

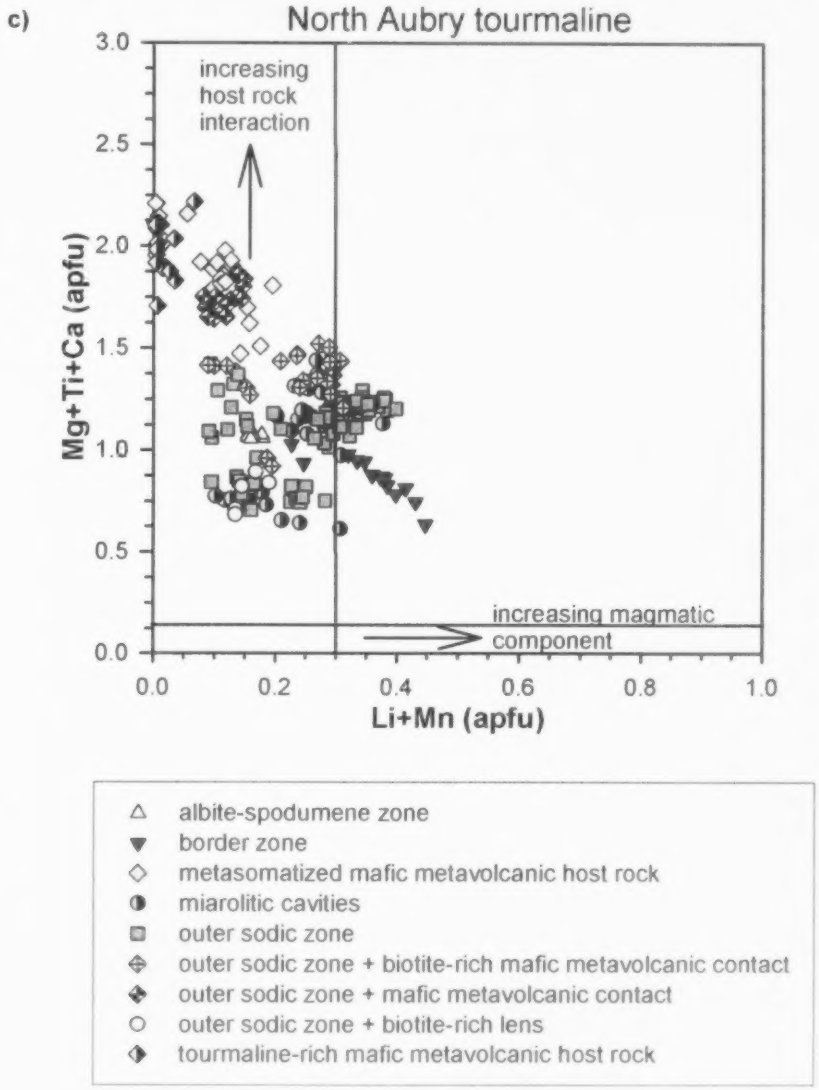

Figure 11, continued. Tourmaline compositional variation from the North Aubry pegmatite: c) Li+Mn (*apfu*) versus Mg+Ti+Ca (*apfu*).

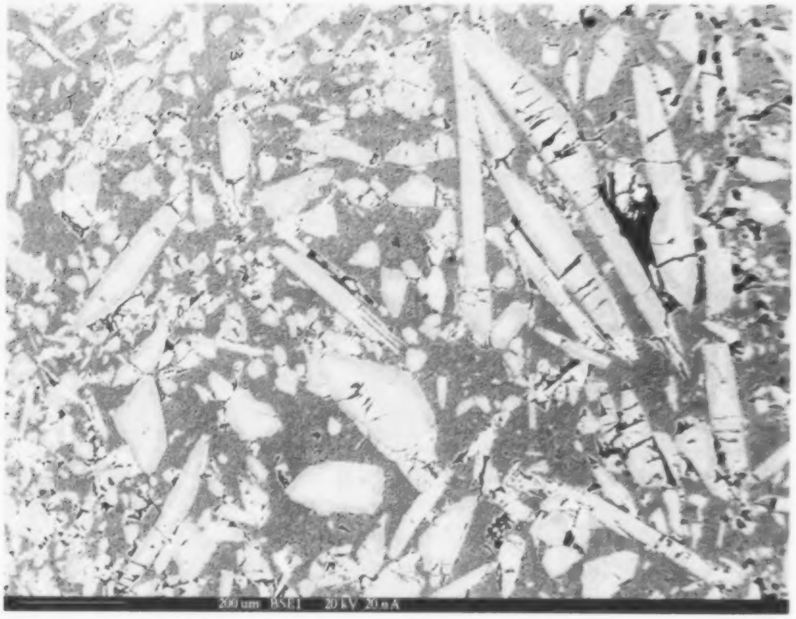
200 um BSE1 20 kV 20 nA

Photo 17. Zoned tourmaline crystals from quartz-tourmaline intergrowth near lower pegmatite–mafic metavolcanic contact. Trench NA-4 (locality 01-AGT-10-09).

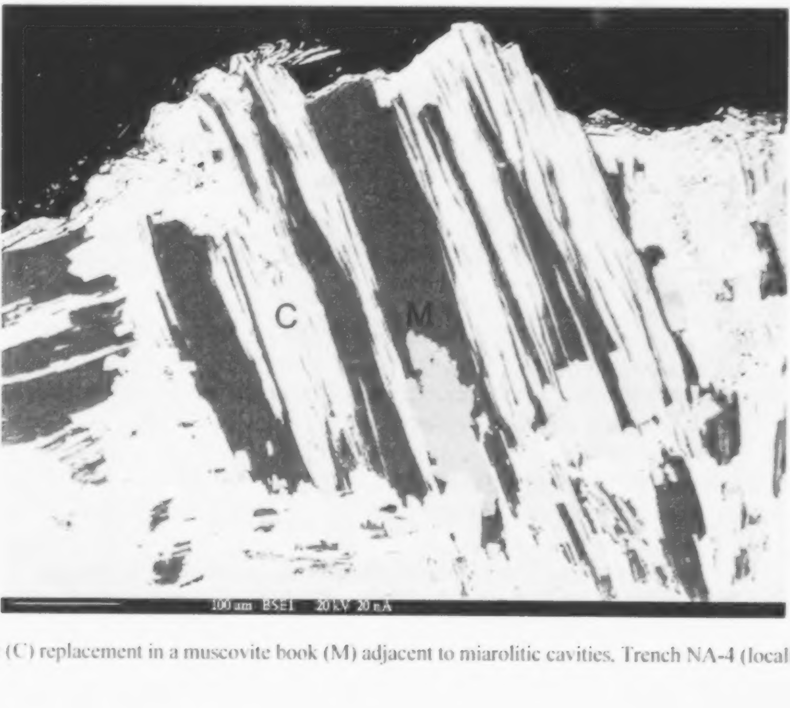
C
M
100 um BSE1 20 kV 20 nA

Photo 18. Cookeite (C) replacement in a muscovite book (M) adjacent to miarolitic cavities. Trench NA-4 (locality 01-AGT-10-09).

MIAROLITIC CAVITIES

The 2 miarolitic cavities in Trench NA-4 contain white potassium feldspar, green muscovite and prismatic coarse-grained black tourmaline (up to 1.6 cm long) coated by unidentified beige clay minerals. The tourmaline is zoned with magnesium-rich foitite-schorl cores and schorl-dravite and dravite-schorl rims (*see* Figures 11a, 11b and 11c). Thus, the tourmaline cores are iron rich and the rims are magnesium, sodium and fluorine rich.

White cesium-rich beryl, which occurs in a cleavelandite-rich mass adjacent to quartz, contains tiny inclusions of primary uranium-bearing microlite (UO_2 = 2.15 to 3.47 weight %, Ta_2O_5 = 71.50 to 75.10 weight %). Cookeite (lithium-chlorite) occurs along the margins of the beryl as a late secondary phase that partially replaces muscovite books (Photo 18). Fluorapatite (MnO = 0.11 to 0.68 weight %) inclusions occur in cleavelandite, and the mica contains muscovite cores (Rb_2O = 0.43 to 0.79 weight %, Cs_2O = 0.09 to 0.11 weight %) and lepidolite rims.

The minerals in the miarolitic cavities crystallized from a late-stage exsolved fluid that was possibly spurred by crystallization of tourmaline (London 1987). Enrichment in several elements is indicated by the mineralogy of the cavities: magnesium (tourmaline rims), calcium (microlite, fluorapatite), fluorine (tourmaline rims, microlite, fluorapatite, lepidolite rims), sodium (tourmaline rims, albite, beryl) and cesium (beryl).

INTERNAL PEGMATITE UNITS

Quartz-Muscovite Zone (3)

The muscovite in the quartz-muscovite zone is modestly evolved as indicated by levels of Rb_2O (0.91 to 1.79 weight %) and Cs_2O (0.10 to 0.41 weight %). The accessory minerals comprise manganocolumbite, manganotantalite, fluorapatite and beryl. The fluorapatite (*see* Figure 10) reveals a wide range in MnO contents (0.24 to 6.02 weight %). The pale green to white beryl (Figure 12) contains low Cs_2O (0.32 to 0.47 weight %) and Na_2O contents (0.96 to 1.63 weight %).

Muscovite-rich Pods (4)

The muscovite-rich pods in Trench NA-2 contain silver, coarse-grained muscovite, lepidolite and approximately 5 volume % of interstitial quartz and albite. The mica has less evolved muscovite cores (Rb_2O = 0.66 to 1.61 weight %, Cs_2O = 0.03 to 0.68 weight %, MnO = 0.23 to 0.91 weight %) and irregular areas of lepidolite replacement (Photo 19) with overlapping but generally higher Rb_2O = (1.47 to 2.22 weight %), Cs_2O (0.46 to 1.35 weight %) and MnO (0.58 to 1.60 weight %).

Accessory Ta-Nb oxide minerals and blue fluorapatite (MnO = 0.55 to 5.45 weight %) occur along the edge of the muscovite-rich pods. The fluorapatite is zoned with MnO-rich cores (4.46 to 4.62 weight %) and MnO-poor rims (2.20 to 0.55 weight %). The muscovite cores, oxide minerals and the fluorapatite are modestly evolved and indicate relatively early crystallization followed by formation of lepidolite-rich rims on muscovite and MnO-rich rims on fluorapatite most likely generated via reaction with late-stage fluids.

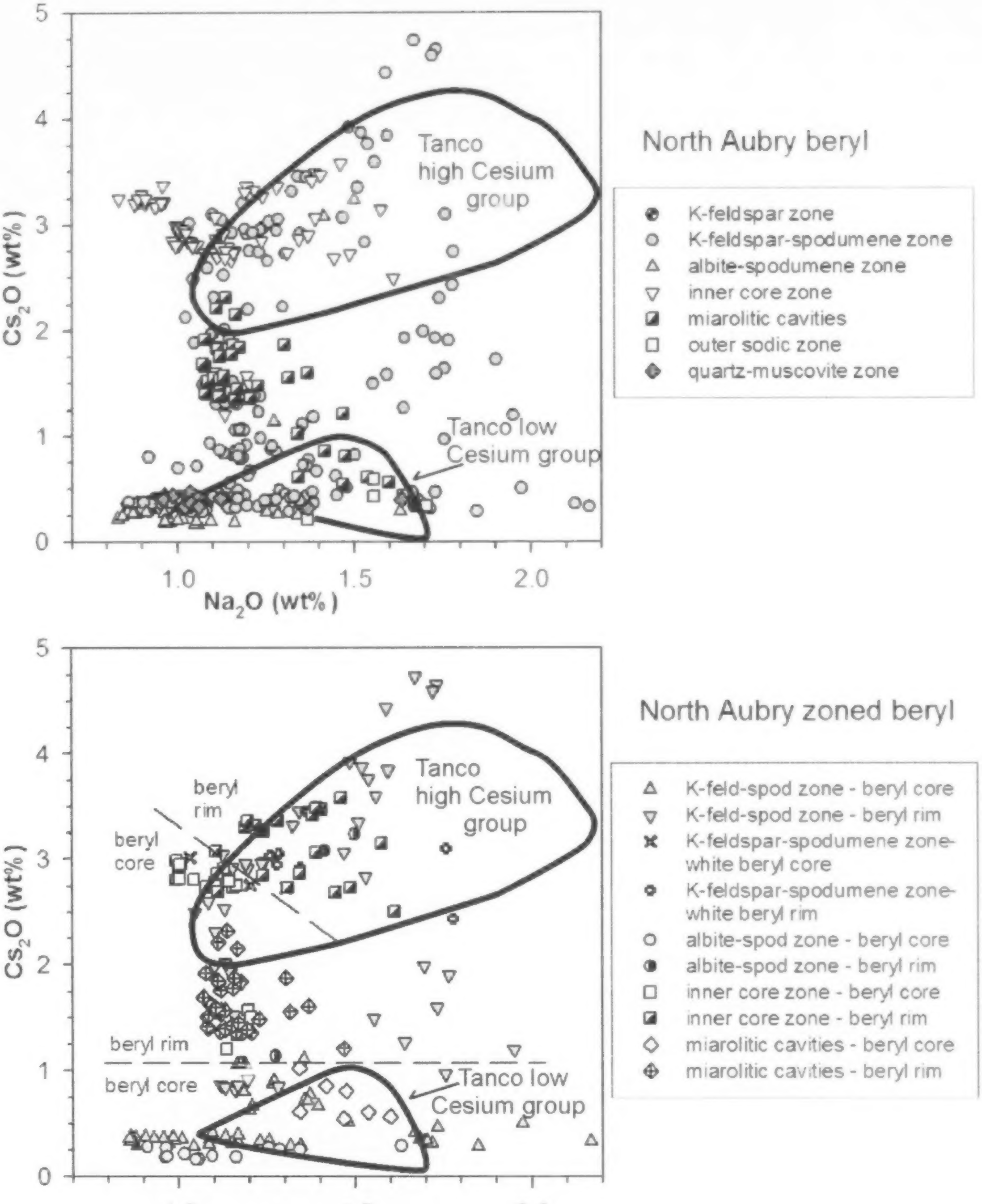

Figure 12. Sodium oxide (Na_2O) versus cesium oxide (Cs_2O) (weight %) compositional variation in beryl from various internal zones of the North Aubry pegmatite.

Potassium Feldspar Zone (6)

The potassium feldspar zone is characterized by the abundance of blocky potassium feldspar and can be subdivided into 3 petrographic variants: unaltered crystals and those affected by hematization and albitization. The unaltered potassium feldspar is Rb_2O rich (1.09 to 1.56 weight %) and Cs_2O rich (0.10 to 1.9 weight %). The accessory Ta-Nb oxide minerals comprise ferrocolumbite, manganocolumbite and manganotantalite and are more iron rich than those in the albitized potassium feldspar zone.

The albitized parts of the potassium feldspar zone contain manganocolumbite to manganotantalite. The blue green fluorapatite in the unaltered potassium feldspar zone (*see* Figure 10) contains moderate amounts of MnO (3.12 to 4.46 weight %). The beryl in the albitized and unaltered potassium feldspar zones is commonly green and contains modest levels of Na_2O (0.86 to 1.26 weight %) and Cs_2O (0.29 to 0.42 weight %), as shown in Figure 12.

Albite-Spodumene Zone (7)

The albite-spodumene zone contains abundant albite (aplite and cleavelandite), spodumene and quartz and accessory manganocolumbite and manganotantalite. The blue fluorapatite (*see* Figure 10) generally contains MnO contents that exceed 3 weight % within a wide range (0.82 to 5.59 weight %).

Beryl is modestly evolved (*see* Figure 12) with a wide range in Na_2O (0.83 to 1.63 weight %) and low Cs_2O (0.17 to 0.29 weight %) and is typically green. Zoned green beryl in 02-JBS-41-02 has low Cs_2O levels in the core (0.20 to 0.29 weight %) *vis-à-vis* the rim (1.14 to 3.23 weight %). This beryl is contained in an assemblage with muscovite and fluorapatite that ostensibly replaces part of a 1.4 m long spodumene crystal in Trench NA-6. Minor potassium feldspar in the albite-spodumene zone is enriched in Rb_2O (1.06 to 1.46 weight %) and Cs_2O (0.04 to 0.31 weight %).

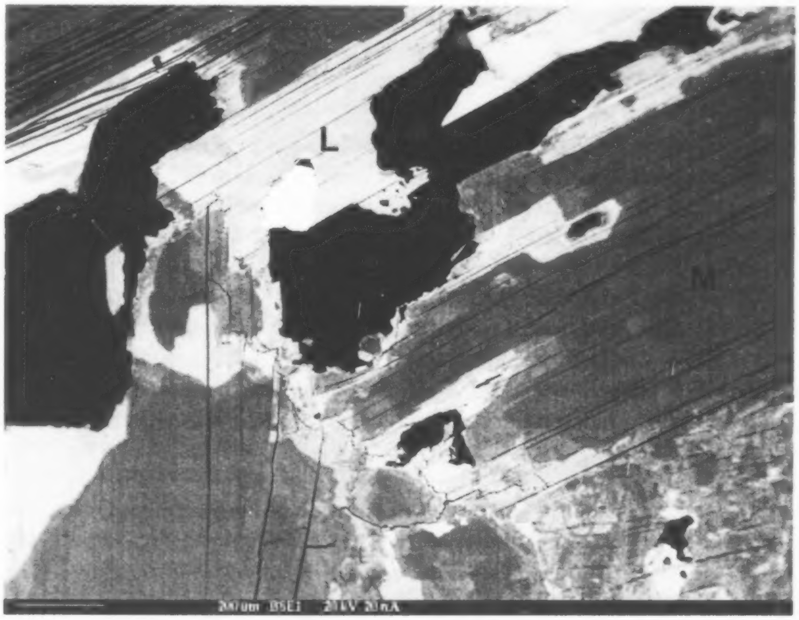

Photo 19. Muscovite (M) replaced by lepidolite (L) from the margins of a muscovite-rich pod, Trench NA-2 (locality 02-JBS-43-03). Dark areas represent holes in the polished grain mount.

Potassium Feldspar Zone (6)

The potassium feldspar zone is characterized by the abundance of blocky potassium feldspar and can be subdivided into 3 petrographic variants: unaltered crystals and those affected by hematization and albitization. The unaltered potassium feldspar is Rb_2O rich (1.09 to 1.56 weight %) and Cs_2O rich (0.10 to 1.9 weight %). The accessory Ta-Nb oxide minerals comprise ferrocolumbite, manganocolumbite and manganotantalite and are more iron rich than those in the albitized potassium feldspar zone.

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The albite-spodumene zone contains abundant albite (aplite and cleavelandite), spodumene and quartz and accessory manganocolumbite and manganotantalite. The blue fluorapatite (*see* Figure 10) generally contains MnO contents that exceed 3 weight % within a wide range (0.82 to 5.59 weight %).

Beryl is modestly evolved (*see* Figure 12) with a wide range in Na_2O (0.83 to 1.63 weight %) and low Cs_2O (0.17 to 0.29 weight %) and is typically green. Zoned green beryl in 02-JBS-41-02 has low Cs_2O levels in the core (0.20 to 0.29 weight %) *vis-à-vis* the rim (1.14 to 3.23 weight %). This beryl is contained in an assemblage with muscovite and fluorapatite that ostensibly replaces part of a 1.4 m long spodumene crystal in Trench NA-6. Minor potassium feldspar in the albite-spodumene zone is enriched in Rb_2O (1.06 to 1.46 weight %) and Cs_2O (0.04 to 0.31 weight %).

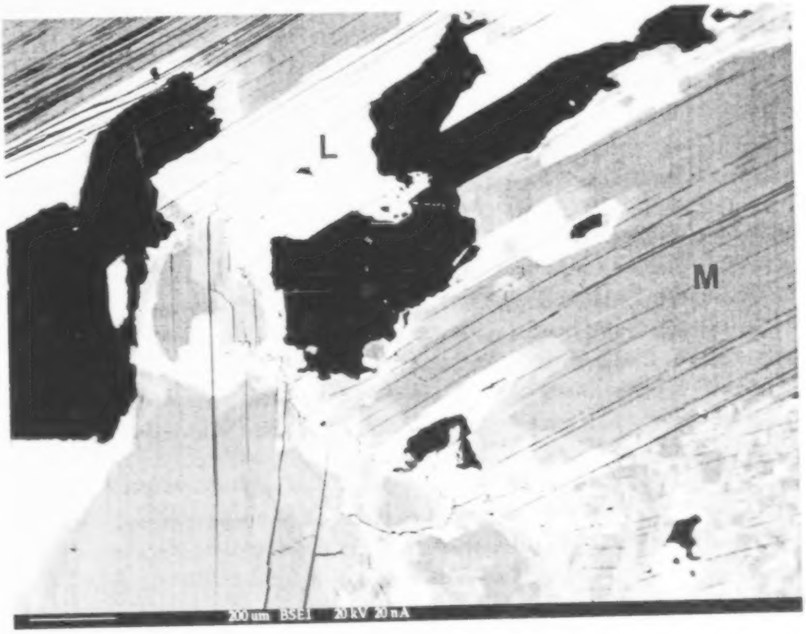

Photo 19. Muscovite (M) replaced by lepidolite (L) from the margins of a muscovite-rich pod. Trench NA-2 (locality 02-JBS-43-03). Dark areas represent holes in the polished grain mount.

Garnet occurs only along the contact between albite-spodumene zone (cleavelandite) and outer sodic aplite zone in 02-JBS-41-08 from Trench NA-6 (*see* Figures 9a and 9b) and consists mostly of spessartine (72 to 82%) and almandine (17 to 27%).

Potassium Feldspar-Spodumene Zone (8)

The potassium feldspar-spodumene zone is the most widespread internal unit and contains white, blocky potassium feldspar, coarse-grained green spodumene and common, coarse-grained green beryl. The oxides are manganocolumbite to tantalum-rich manganotantalite and rare microlite. Fluorapatite MnO contents (*see* Figure 10) reveal a wide range (0.28 to 7.42 weight %) and average 4.95 weight %. Zoned fluorapatite, in 02-JBS-41-25 exhibits relatively MnO-poor cores (2.95 to 3.34 weight %) and MnO-rich rims (6.75 to 6.95 weight %). Minor red-brown lithiophilite ($LiMnPO_4$) was identified by X-ray diffraction. Spodumene in this pegmatite zone contains minor amounts of iron (0.33 to 0.98 weight % Fe_2O_3). Rare garnet, as in 02-JBS-32-09 from Trench SA-5, consists of spessartine (76 to 84%) and subordinate almandine (14 to 22%).

Green beryl in the potassium feldspar-spodumene zone (*see* Figure 12: filled circles in upper diagram; filled triangles in lower diagram) contains a wide range of Na_2O (0.86 to 2.17 weight %) and Cs_2O (0.28 to 4.73 weight %) and is typically zoned with cesium-poor cores and cesium-rich rims. For example, 01-FWB-87-14 contains zoned green beryl with Cs_2O-poor cores (0.28 to 0.67 weight %) and Cs_2O-rich rims (1.93 to 3.07 weight %). Zoned coarse-grained green beryl (7 cm across) in 02-JBS-44-02 reveals the highest rim contents of Cs_2O (1.52 to 4.73 weight %) in this zone.

The mica minerals are commonly zoned with cores depleted and rims enriched in MnO, Rb_2O and Cs_2O. For example, the muscovite core in 01-AGT-10-07 from Trench NA-4 contains levels of MnO (0.50 to 0.65 weight %), Rb_2O (1.26 to 1.49 weight %) and Cs_2O (0.10 to 0.15 weight %) that simultaneously increase in the lepidolite rim (MnO = 0.86 to 1.44 weight %, Rb_2O = 1.91 to 2.17 weight % and Cs_2O = 0.27 to 0.52 weight %).

Corona Zone (9)

The purple mica, which is found in the aplite matrix enveloping the coronas, was identified as muscovite rather than lepidolite by electron microprobe and X-ray diffraction work. This is corroborated by the low bulk rock lithium contents in the purple muscovite-aplite matrix from Trench NA-5 (samples 02-FWB-15 and 02-FWB-16: *see* Tindle, Selway and Breaks 2006 (MRD 210), Table 4).

The purple muscovite is enriched in MnO (0.19 to 1.50 weight %), Rb_2O (0.64 to 1.84 weight %) and Cs_2O (0.03 to 0.50 weight %). The distinctive colour of the muscovite is due to the elevated Mn content and/or the red staining of hematite along the edges of the muscovite crystals. However, this muscovite is less evolved than its counterparts in the potassium feldspar-spodumene and inner core zones. The purple muscovite-aplite matrix contains minor, altered uranium-rich microlite (10.08 weight % UO_2) mantled by magnetite.

Three types of apatite occur within the purple muscovite-aplite matrix: MnO-poor fluorapatite (0.04 to 2.19 weight %), MnO-poor carbonate-fluorapatite (0.12 to 1.06 weight %) and FeO- and REE-bearing carbonate-fluorapatite (MnO = 1.22 to 1.77 weight %, La_2O_3 = 0.10 to 0.19 weight % Ce_2O_3 = 0.05 to 0.14 weight %). The blue manganese-rich fluorapatite within the coronas has a wide range in MnO contents (2.74 to 8.68 weight %) that is generally higher compared to fluorapatite in the purple muscovite-aplite matrix.

Inner Core Zone (10)

The fluorapatite has 2 distinct compositions (*see* Figure 10): MnO-poor (0.28 to 2.66 weight %) and MnO-rich (6.54 to 7.56 weight %). Zoned fluorapatite was found in 01-AGT-10-18 with MnO-poor cores (0.91 to 1.39 weight %) and MnO-enriched rims (1.78 to 2.66 weight %). The spodumene is manganese poor with MnO = 0.04 to 0.24 weight %. Rare garnet in the inner core zone is almost pure end-member spessartine (97 to 100% spessartine) with only 2% almandine and 1% pyrope. Rare orange lithiophilite, confirmed by X-ray diffraction, is MnO rich (39.55 to 41.01 weight %) with the average Mn/(Mn+Fe) = 0.90.

Pink beryl (*see* Figure 12) contains moderate amounts of Na_2O (0.83 to 1.61 weight %) and is Cs_2O rich (1.21 to 3.58 weight %). Most of the beryl is zoned with relatively Cs_2O-poor cores and Cs_2O-rich rims as exemplified by 02-JBS-36-03 (cores = 1.21 to 1.57 weight % and rims = 2.50 to 3.07 weight %).

Thirteen bulk compositions of potassium feldspar from the North Aubry pegmatite (Table 4 and summarized in Table 5: *see* Tindle, Selway and Breaks 2006 (MRD 210)), indicate pronounced enrichment in Rb_2O (mean = 1.14; range 1.01 to 1.23 weight %) and modest Cs_2O (mean = 0.06; range 0.03 to 0.12 weight %). The very low K/Rb (mean = 10.6) and K/Cs (mean = 225) ratios in the potassium feldspar compare with other highly evolved, complex-type pegmatites in the Superior Province of Ontario (Breaks, Selway and Tindle 2005).

Electron microprobe compositions of beige, blocky primary potassium feldspar reveal similar enrichment in Rb_2O (1.32 to 1.64 weight %) and Cs_2O (0.02 to 0.08 weight %). The mica in the inner core zone, which is dominantly muscovite, contains modest amounts of MnO (0.08 to 1.00 weight %) with a similar range in Rb_2O (0.79 to 1.95 weight %) and higher contents of Cs_2O (0.13 to 0.37 weight %).

Petrochemistry of the North Aubry Pegmatite

Rare-element-rich fluids (i.e., rubidium, cesium, and lithium) and potassium- and boron- rich fluids migrated from the pegmatite melt into the host rocks and reacted to produce "biotite"-, tourmaline- and holmquistite-bearing metasomatic aureoles. The potassium metasomatism, which produced high modal concentrations of "biotite", is ubiquitous, whereas boron and lithium-rich pegmatite fluids only resulted in localized tourmaline and holmquistite. The "biotite" has a composition of siderophyllite-zinnwaldite and is rich in lithium, rubidium, cesium and fluorine (Breaks, Selway and Tindle 2003a). A distinctive blue colouration due to high concentrations of randomly oriented holmquistite (lithium-rich amphibole) needles is locally apparent. A 20 cm long channel sample across one of the holmquistite-rich mafic metavolcanic pillows (02-JBS-38-15: *see* Tindle, Selway and Breaks 2006 (MRD 210), Table 4) contains anomalous Li (5420 ppm) and Cs (6047 ppm) that indicates significant migration of these elements, in particular, during the metasomatic process.

The metasomatized host rocks exhibit depletion in CaO, Fe_2O_3, MgO and Na_2O and enrichment in K_2O, LOI, Rb, Cs, and Li that manifested through interaction with the pegmatite-forming melt. This depletion–enrichment pattern was established in a series of bulk rock samples of homogeneous mafic metavolcanic rocks with increasing distance above the flat-lying contact of the pegmatite as exposed in Trench NA-5-6 (*see* Tindle, Selway and Breaks 2006 (MRD 210), Table 4). There is a modest depletion of CaO, MgO and total iron as Fe_2O_3 and drastic decrease in Na_2O within the first sample interval (0 to 5 cm) of the mafic metavolcanic rocks adjacent to the pegmatite. Conversely, K_2O, Li, Rb, and Cs exhibit high concentrations within 55 cm of the pegmatite contact, attesting to the outflow of these elements during exomorphism.

Several samples of biotite-rich (>90 volume %) selvages from elsewhere in the North Aubry (Trench NA-5) and South Aubry pegmatites (*see* Tindle, Selway and Breaks 2006 (MRD 210), Table 4) have similar depletion–enrichment features, marked by a modest decrease in total iron, MgO and Na_2O and a profound depletion of CaO (0.36 to 0.46 weight %) versus 11.5 to 14.5 weight % at distances greater than 4 m from the pegmatite contact. The movement of CaO into the pegmatite-forming melt was balanced, in part, by a significant egress of K_2O (6.82 to 9.43 weight %) into the mafic metavolcanic host that typically contains 0.1 to 0.3 weight % K_2O in areas unaffected by pegmatite exomorphism.

The siderophyllite-zinnwaldite-rich, metasomatized host rocks in Trench NA-5 immediately adjacent to the pegmatite contact are unusually rich in rare-elements as revealed by the following ranges in bulk rock compositions (*see* Tindle, Selway and Breaks 2006 (MRD 210), Table 4): Li_2O (1.63 to 1.75 weight %), Rb_2O (1.36 to 2.0 weight %), Cs_2O (1.07 to 1.24 weight %), Nb (6 to 40 ppm) and Ta (4 to 74 ppm), coupled with extremely low K/Rb (3.0 to 3.1) and K/Cs (3.1 to 5.6) ratios (Tindle, Selway and Breaks 2002).

The holmquistite-rich metasomatized host rocks in Trench NA-5 (*see* Tindle, Selway and Breaks 2006 (MRD 210), Table 4) have lower rare-element contents with Li_2O (1.20 weight %), Rb_2O (0.20 weight %) and Cs_2O (0.64 weight %) with similarly low K/Rb (6.4) and K/Cs (1.8) ratios. The decrease in rare-element contents from the "biotite"- to the holmquistite-rich aureoles relates to the higher contents of Rb and Cs that can be accommodated in siderophyllite-zinnwaldite *vis-à-vis* holmquistite.

Aplites from the North Aubry pegmatite have contents of Rb (mean = 649 ppm; range 34 to 2954 ppm) and Cs (mean = 91 ppm; range 8 to 250 ppm) that are dependant upon the modal quantity of muscovite and potassium feldspar that are typically rare or absent in sodium-rich aplite (Tindle, Selway and Breaks 2002). However, the very low K/Rb (mean = 14.5; range 9 to 39) and K/Cs (mean = 79; range 36 to 162) ratios indicate that the aplites are highly evolved.

Tantalum values in these aplites (mean = 191 ppm; range 62 to 212 ppm) values indicate pronounced enrichment relative to Nb (mean = 106 ppm; range 50 to 150 ppm), resulting in extremely low Nb/Ta ratios (mean = 0.6; range 0.3 to 0.8). Such low Nb/Ta ratios indicate extreme evolution of the pegmatite-forming melts. Thus, bulk compositions of aplites are deemed a good exploration tool to utilize in assessing whether tantalum-rich oxide minerals may exist in various internal units of a lithium-rich pegmatite. In Trench NA-5, the aplite bulk Nb/Ta ratios corroborate the extreme tantalum contents in manganotantalite found in the adjacent inner core zone. Due to its fine grain size, aplite bulk compositions offer useful material to ascertain the tantalum potential of rare-element pegmatite systems.

The inner core zone (10) of the North Aubry pegmatite in Trench NA-5, enveloped by an outer sodic aplite zone, and is the most chemically and mineralogically evolved zone in the entire North Aubry pegmatite. This conclusion is supported by the lowest bulk rock K/Rb (mean = 7.2; range 6.6 to 7.9), K/Cs (mean = 18; range 6 to 33) and Nb/Ta (mean = 0.12; range 0.05 to 0.2) ratios (*see* Tindle, Selway and Breaks 2006 (MRD 210), Table 4; and Tindle, Selway and Breaks 2002). Cesium levels achieve the highest bulk rock levels (mean = 1323 ppm; range 271 to 3284 ppm) and are mostly partitioned into pink, cesium-rich beryl, potassium feldspar and sparse pollucite.

Geology of South Aubry Pegmatite

The South Aubry pegmatite (Figure 13), up to 50 m wide, is similar to North Aubry, as spodumene is the dominant lithium-bearing mineral, but differs in that muscovite is much more abundant. The South Aubry pegmatite can be divided into 4 pegmatite zones:

1. aplite border zone
2. plumose muscovite zone in Trench SA-2
3. beryl-spodumene zone in Trench SA-1
4. albite-spodumene zone. Trench SA-3 reveals alternating albite-spodumene and plumose muscovite layers

The mafic metavolcanic host rocks of the South Aubry pegmatite have been metasomatized by pegmatite-forming fluids, similar to the North Aubry pegmatite, as evident by "biotite"-rich selvages along the pegmatite contacts.

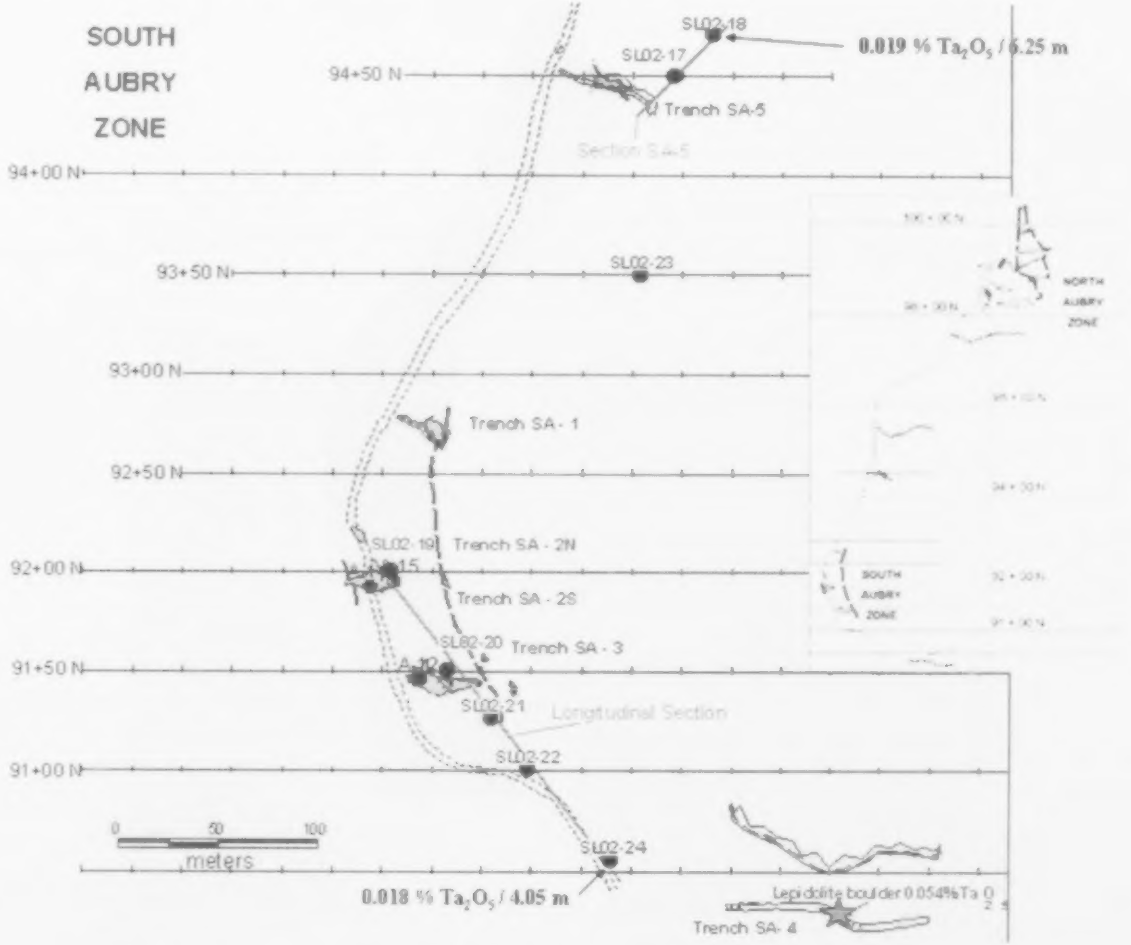
SOUTH
AUBRY
ZONE
SL02-18
SL02-17
0.019 % Ta_2O_5 / 6.25 m
94+50 N
Trench SA-5
Section SA-5
94+00 N
93+50 N
SL02-23
NORTH
AUBRY
ZONE
93+00 N
Trench SA - 1
92+50 N
SL02-19
Trench SA - 2N
92+00 N
15
Trench SA - 2S
SOUTH
AUBRY
ZONE
SL02-20
Trench SA - 3
91+50 N
A-12
SL02-21
Longitudinal Section
SL02-22
91+00 N
0
50
100
meters
SL02-24
0.018 % Ta_2O_5 / 4.05 m
Lepidolite boulder 0.054% Ta_2O_5
Trench SA- 4

Figure 13. Plan view and location of trenches in the South Aubry pegmatite *from* Dimmell and Morgan (2006).

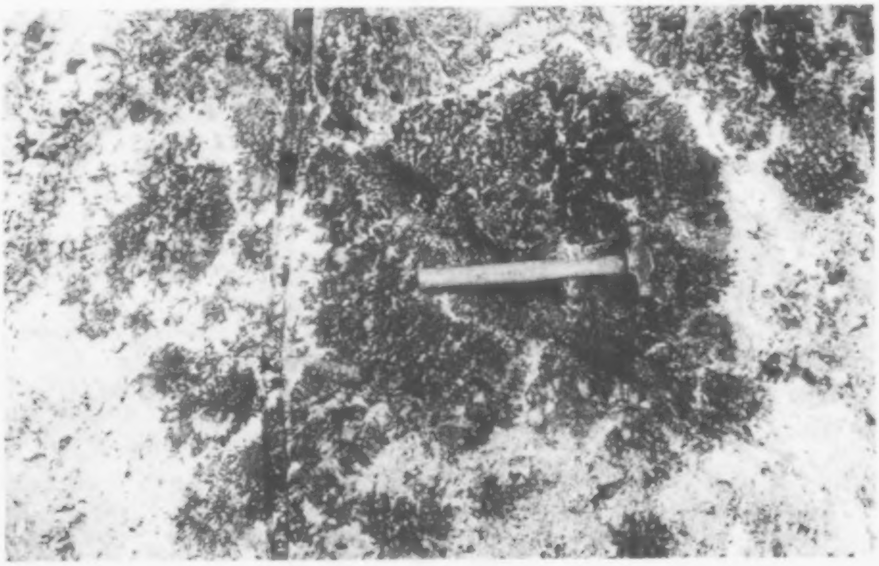

Photo 20. Plumose muscovite zone, Trench SA-3: ovoid symplectite of quartz-muscovite, marked by hammer, within an albite-rich matrix.

Photo 21. Coarse green beryl, quartz megacrysts embedded in a coarse albite-rich matrix. Trench SA-1. Diameter of coin adjacent to large beryl at right = 2.5 cm.

APLITE BORDER ZONE (1)

The relatively minor aplite border zone contains abundant albite and quartz, and minor blue fluorapatite, oxide minerals and muscovite.

PLUMOSE MUSCOVITE ZONE (2)

The South Aubry pegmatite largely consists of a plumose muscovite zone, characterized by impressive ovoid symplectites of quartz-muscovite with interstitial albite (Photo 20). These segregations, up to 1 m in diameter, contain approximately equal amounts of quartz and muscovite and are dominant in Trench SA-2. Green beryl (up to 4 by 3 cm), blue fluorapatite and beige spodumene (30 by 2.5 cm) are sparse in the plumose muscovite zone. Oxide minerals (manganocolumbite and manganotantalite) and garnet are rare in the interstitial albite interstitial.

BERYL-SPODUMENE ZONE (3)

The beryl-spodumene zone of Trench SA-1 is characterized by very coarse-grained, green beryl crystals up to 46 by 34 cm (Photo 21) enveloped by white, coarse-grained albite, quartz and green muscovite. These beryl crystals represent the coarsest yet observed by the writers in any rare-element pegmatite from the Superior Province of Ontario. A cluster of 10 coarse-grained green beryl crystals (>2 cm) occurs at the east end of the trench.

ALBITE-SPODUMENE LAYERS (4)

The albite-spodumene layers contain coarse-grained spodumene, white albite, quartz and beryl. These tabular units, up to 4 m thick in Trench SA-3, are enveloped by albite-spodumene pegmatite and plumose muscovite masses. The green spodumene is very coarse grained and attains lengths up to 56 cm and a thickness up to 6 cm. Beryl only occurs in the albite-spodumene layers and exhibits 2 types of zoning: a) pink rims and white cores and b) green rims and grey cores. The albite-spodumene layers also contain minor blue fluorapatite and radiating blades of manganotantalite up to 1 to 6 mm by 2 cm.

SUMMARY OF THE MINERALOGY OF SOUTH AUBRY PEGMATITE

The plumose muscovite zone (Trench SA-2) and the plumose muscovite layer (Trench SA-3), are highly evolved relative to the aplite border zone, and are interpreted as units of the same pegmatite zone:

- muscovite + quartz intergrowths with interstitial aplite common to both units
- muscovite compositions are similar except for local higher lithium content in the lepidolite rims of the plumose muscovite layer
- fluorapatite compositions overlap

The beryl-spodumene zone (3) in Trench SA-1 and albite-spodumene layer (4) in Trench SA-3 probably crystallized from a common, highly evolved pegmatite melt on the basis of the following observations:

- similar suite of rock-forming minerals (albite, quartz, muscovite, spodumene and beryl)

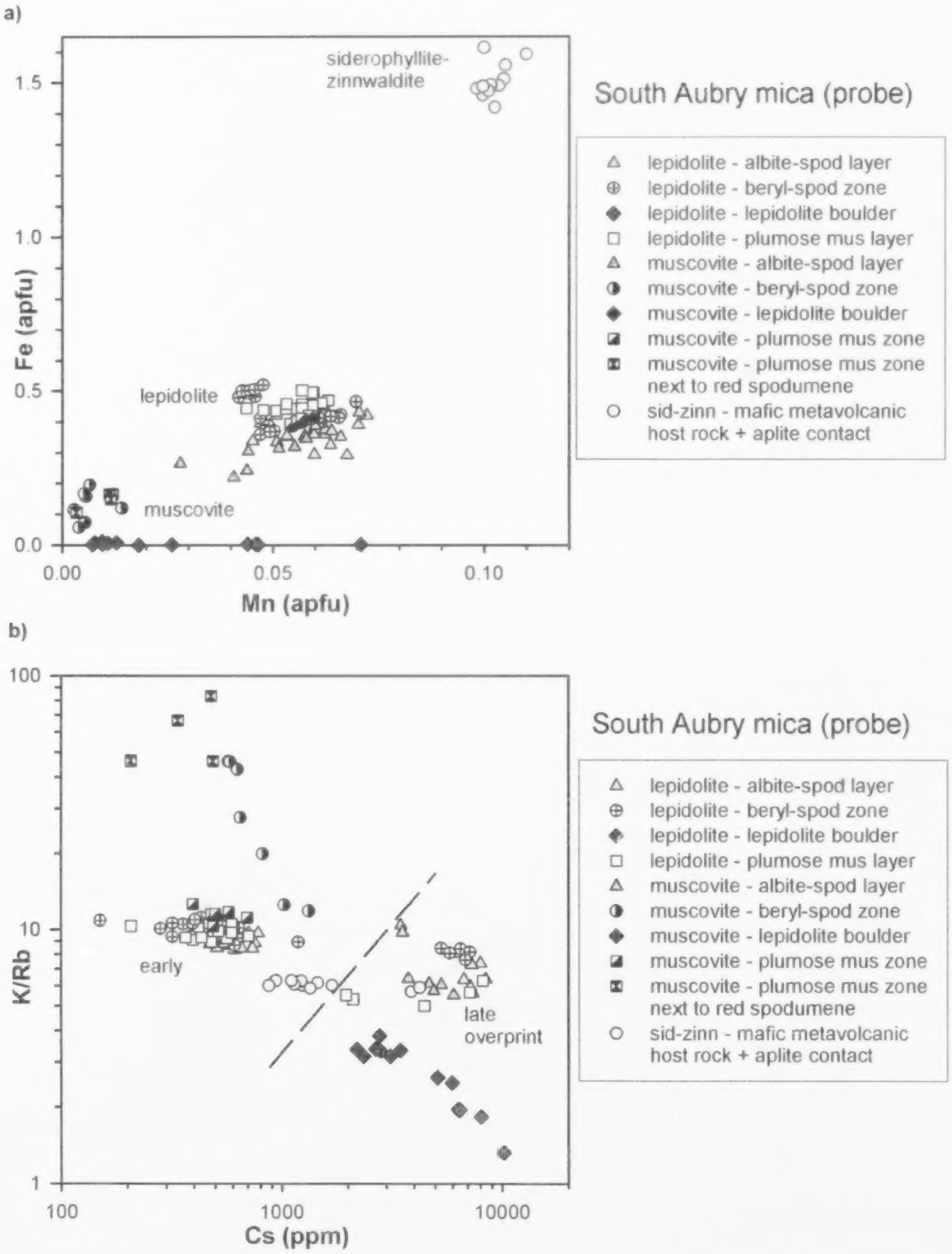

Figure 14. Compositional variation in muscovite, lepidolite and siderophyllite-zinnwaldite from the South Aubry pegmatite: a) manganese (*apfu*) versus iron (*apfu*), and b) cesium (ppm) versus K/Rb.

- beryl compositions are similar in both zones, although beryl is more cesium rich in the albite-spodumene layer
- bimodal lepidolite compositions (cesium poor and cesium rich) occur in both zones
- manganotantalite compositions are similar and highly evolved (up to 93 weight % Ta_2O_5) in both zones, although the manganotantalite is more tantalum rich in the albite-spodumene layer
- MnO-rich fluorapatite common to both zones

Petrochemistry of the South Aubry Pegmatite

Two bulk compositions of "biotite"-rich metasomatized material selected at the pegmatite contact (02-JBS-32-01 and 02-JBS-32-15: *see* Tindle, Selway and Breaks 2006 (MRD 210), Table 4) revealed very high K_2O (7.94 and 9.43 weight %), coupled with significant enrichment in Li_2O (1.48 and 2.48 weight %), Rb_2O (1.08 and 1.80 weight %), and Cs_2O (0.56 and 1.07 weight %) relative to mafic metavolcanic rocks unaffected by pegmatite-derived fluids. These anomalous values signify intense chemical exchange reactions that occurred along the contacts of the South Aubry pegmatite. The egress of these elements and H_2O was probably balanced by influx of Ca, Fe, Mg and Na scavenged from the host rocks.

The aplites from South Aubry pegmatite (*see* Tindle, Selway and Breaks 2006 (MRD 210), Table 4) are modestly anomalous in rare-elements: Li (32 to 76 ppm), Be (12 to 243 ppm), Rb (39 to 161 ppm), Cs (19 to 88 ppm), Nb (4 to 72 ppm) and Ta (7 to 50 ppm) (Tindle, Selway and Breaks 2002). The evolved nature of this pegmatite unit is better revealed by the key fractionation ratios: K/Cs (15 to 170), K/Rb (27 to 34), Rb/Cs (0.5 to 5) and Nb/Ta (0.5 to 1.4). Li, Rb and Cs, in particular, do not achieve high concentrations due to the albite-dominant mineralogy. The elevated Nb and Ta contents and the low Nb/Ta ratio indicate that South Aubry pegmatite is highly evolved and thus has economic potential for tantalum mineralization.

Mineral Chemistry of the South Aubry Pegmatite

The "biotite" in the metasomatized mafic metavolcanic host rock is an iron-, magnesium, and rare-element-rich siderophyllite-zinnwaldite similar to that found at the North Aubry pegmatite (compare Figures 8 and 14a). Comparable levels of Rb_2O (1.35 to 1.46 weight %), Cs_2O (0.09 to 0.45 weight %) and F (2.5 to 2.8 weight %) were documented in siderophyllite-zinnwaldite at the South Aubry pegmatite. The fluorapatite along the contact between the aplite border zone and mafic metavolcanic host rocks is MnO poor (0.16 to 0.36 weight %) (Figure 15).

PLUMOSE MUSCOVITE ZONE (2)

The plumose muscovite zone in Trench SA-2 is characterized by the abundance of muscovite-quartz intergrowths embedded within an albite-rich matrix. The green muscovite has 2 distinct compositions (*see* Figures 14a and 14b):

a) iron-, magnesium-, rubidium-, and manganese-poor muscovite (FeO = 0.94 to 1.48 weight %, MgO = 0.32 to 0.44 weight %, MnO up to 0.10 weight %, Rb_2O = 0.12 to 0.22 weight %, Cs_2O = 0.02 to 0.05 weight %)

b) iron-, magnesium-, rubidium- and manganese-enriched muscovite (FeO = 3.46 to 3.68 weight % FeO, MgO =1.54 to 1.71 weight % MgO, MnO = 0.47 to 0.52 weight % MnO, Rb_2O = 0.76 to 0.92 weight %, Cs_2O = 0.04 to 0.07 weight %)

The muscovite with low rubidium contents is associated with hematite-coated spodumene crystals. The relatively rubidium-rich muscovite occurs within the muscovite+quartz intergrowths and has a similar composition to the lepidolite in the plumose muscovite layer in Trench SA-3. The interstitial aplite contains accessory fluorapatite (*see* Figure 15) with 1.30 weight % MnO and cesium-poor beryl (Figure 16) with 0.12 to 0.55 weight % Cs_2O with a wide range in Na_2O contents (0.80 to 1.80 weight %). The composition of the muscovite, fluorapatite and beryl in this pegmatite zone indicate that the zone is moderately evolved.

The mineralogy of the plumose muscovite layer in Trench SA-3 is very similar to the plumose muscovite zone in Trench SA-2 and likely crystallized from the same pegmatite-forming melt. The coarse-grained green mica in the plumose intergrowth has a composition of lepidolite (*see* Figure 14a) with moderate FeO (3.85 to 4.40 weight %), MgO (1.44 to 2.10 weight %), MnO (0.38 to 0.55 weight %), Rb_2O (0.89 to 1.76 weight %) and Cs_2O (up to 0.87 weight %).

The lepidolite at 01-JBS-44-07 is zoned with cores relatively low in Rb_2O (0.89 to 1.03 weight %) and Cs_2O (0.02 to 0.08 weight %) and rims rich in Rb_2O (1.40 to 1.76 weight %) and Cs_2O (0.21 to 0.87 weight %). This zonation relates to fractionation of the pegmatite-forming melt that increased the rubidium and cesium contents in the melt during crystallization.

Textural evidence reveals a later replacement of muscovite by lepidolite. The process that caused the formation of lepidolite rims on primary muscovite is not straightforward, but could involve 2 mechanisms: i) albitization by fluids whose origin is magmatic and derived from fractionation of the pegmatite-forming melt and are the last residues of the magmatic process, and ii) interaction with hydrothermal fluids due to a magmatic component that circulated into the country rocks, mixed with meteoric waters and returned into the pegmatite as part of a large convective cell. This would have probably happened after the pegmatite had fully crystallized and was much cooler.

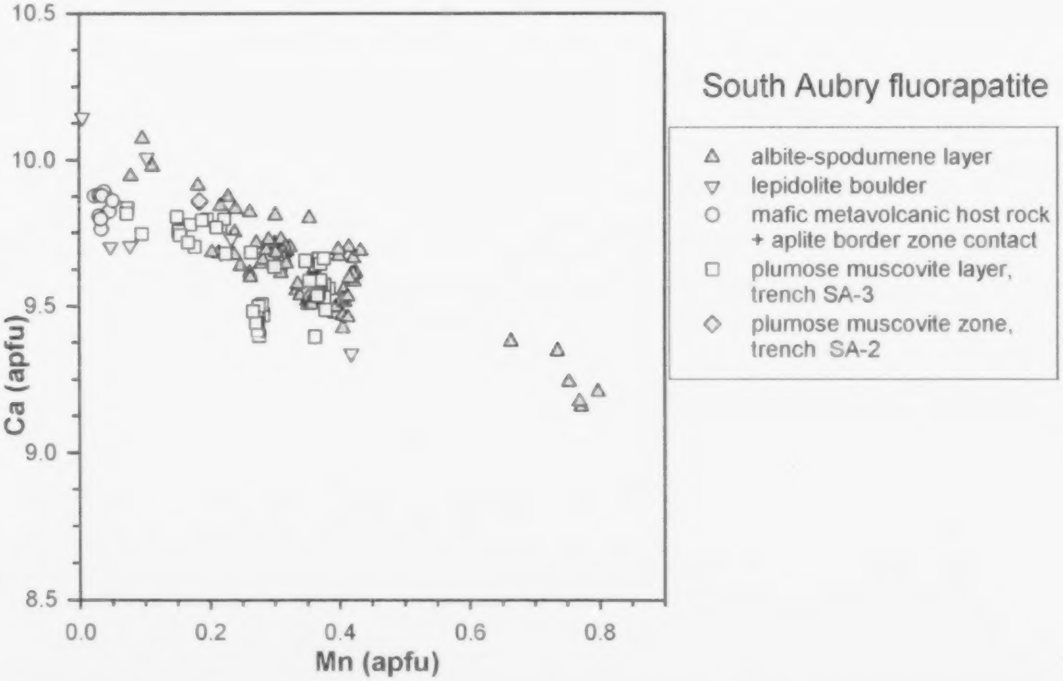

Figure 15. Fluorapatite composition variation as manganese (*apfu*) versus calcium (*apfu*) for various internal zones of the South Aubry pegmatite and the lepidolite boulder in Trench SA-4.

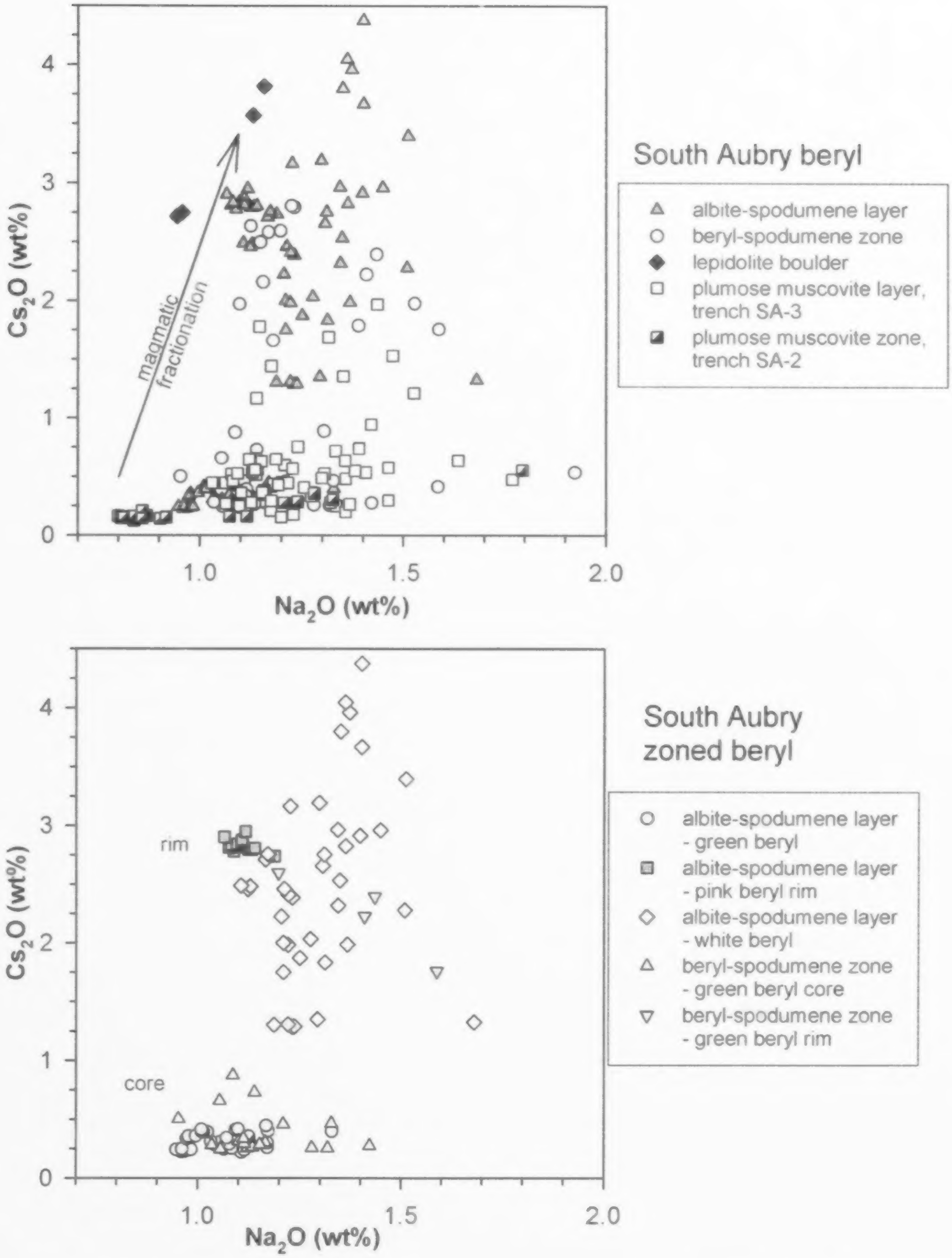

Figure 16. Sodium oxide (Na_2O) versus cesium oxide (Cs_2O) (weight %) in beryl from various internal zones of the South Aubry pegmatite.

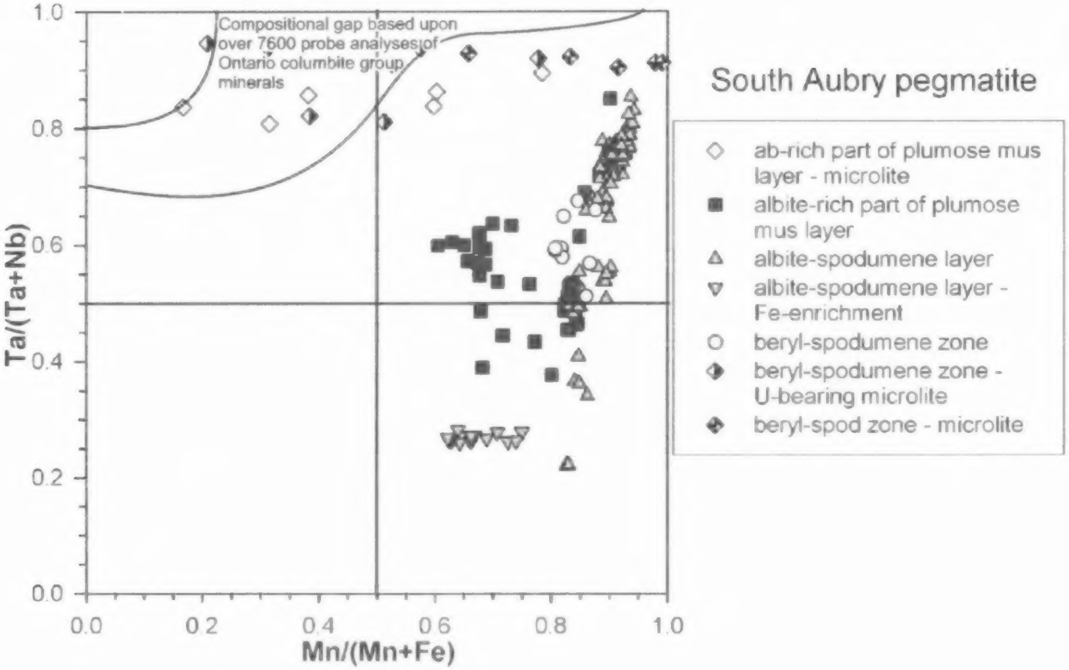

Figure 17. Columbite-tantalite quadrilateral plot (atomic ratios) for various internal zones of the South Aubry pegmatite. Compositional gap between ferrotapiolite and ferrotantalite is based upon 7600 compositions of columbite-tantalite from Ontario. Microlite compositions may plot within this compositional space.

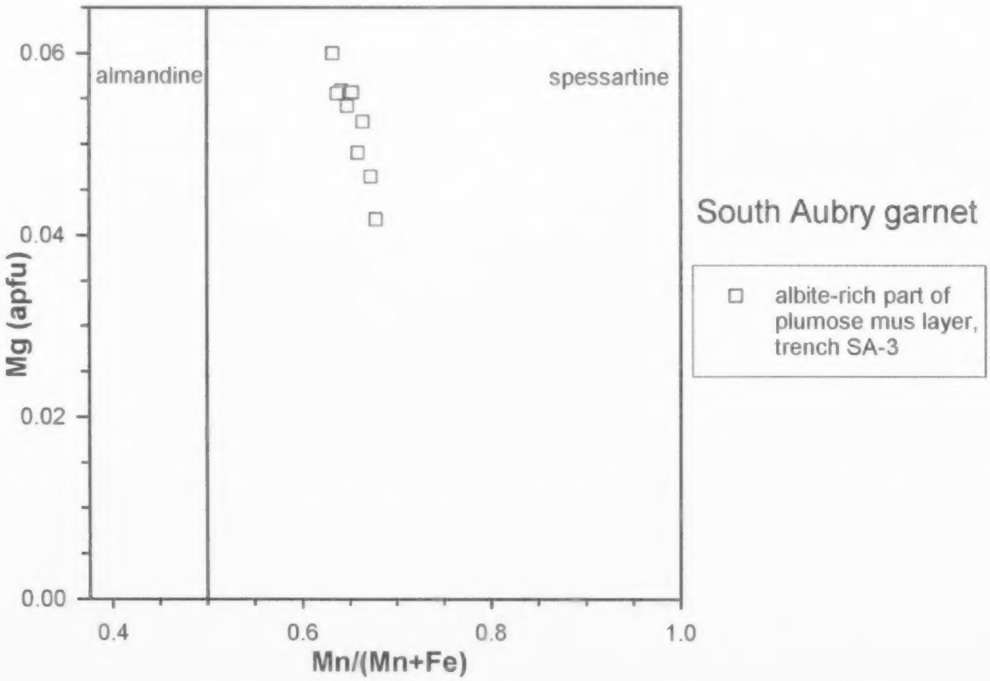

Figure 18. Mn/Mn+Fe versus magnesium (*apfu*) in garnet from the South Aubry pegmatite.

The interstitial aplite between the muscovite-quartz intergrowths in Trench SA-3 contains accessory Ta-Nb oxide minerals, garnet, fluorapatite and beryl. The oxide minerals are oscillatory zoned manganocolumbite to manganotantalite (Figure 17) with a range of Ta_2O_5 (41.03 to 76.96 weight %) and Mn/(Mn+Fe) = 0.61 to 0.90. Zoned oxide grains with a manganocolumbite core (50.62 weight % Ta_2O_5), and a manganotantalite rim (76.96 weight % Ta_2O_5) were documented at 02-JBS-26-17. The manganocolumbite-manganotantalite grains are mantled or replaced by microlite (67.24 to 71.99 weight % Ta_2O_5 and 0.17 to 2.12 weight % UO_2).

The garnet (Figure 18) is spessartine rich (62 to 67%) with moderate amounts of iron (30 to 34% almandine). The blue fluorapatite (*see* Figure 15) contains moderate amounts of MnO (0.51 to 2.67 weight %). The green beryl (*see* Figure 16) contains a wide range in Rb_2O (1.03 to 1.77 weight %) and Cs_2O (0.15 to 1.97 weight %).

BERYL-SPODUMENE ZONE (3)

The beryl-spodumene zone in Trench SA-1 is characterized by an abundance of very coarse-grained, green beryl enveloped by albite, quartz and green muscovite and minor spodumene. The green beryl (*see* Figure 16), which has a wide range in compositions (Na_2O = 0.95 to 1.92 weight %, Cs_2O = 0.25 to 2.81 weight %), is the coarsest observed by the writers in the Superior Province of Ontario (*see* Photo 21). Zoned beryl at 01-JBS-40-08 contains Cs_2O-poor cores (0.25 to 0.88 weight %) and Cs_2O-rich rims (1.76 to 2.60 weight %).

Three distinct mica compositions occur in the beryl-spodumene zone:

- Rb_2O-poor muscovite
- Cs_2O-poor lepidolite
- Cs_2O-rich lepidolite

The rubidium-poor muscovite contains 0.21 to 0.80 weight % Rb_2O and 0.06 to 0.14 weight % Cs_2O and low iron and magnesium contents. Both types of lepidolite are enriched in iron and magnesium (FeO = 3.16 to 4.55 weight %, MgO = 1.27 to 2.11 weight %) that indicates late-stage contamination of the pegmatite melt. The cesium-poor lepidolite contains Rb_2O (0.83 to 1.05 weight %) and Cs_2O (0.02 to 0.13 weight %), whereas the cesium-rich lepidolite contains Rb_2O (1.06 to 1.19 weight %) and Cs_2O (0.56 to 0.76 weight %).

The accessory Ta-Nb oxide minerals (*see* Figure 17), as exemplified by 02-JBS-29-01, comprise oscillatory zoned manganotantalite (53.33 to 65.10 weight % Ta_2O_5) partially replaced by microlite (73.95 to 76.65 weight % Ta_2O_5 and 0.17 to 0.51 weight % UO_2). Euhedral, metamict, uranium-bearing microlite, associated with hematite-coated spodumene, occurs at 01-JBS-40-08 and contains 61.07 to 70.29 weight % Ta_2O_5 and 4.48 to 6.52 weight % UO_2). The beryl-spodumene zone crystallized from a highly fractionated pegmatite-forming melt as indicated by coarse-grained beryl with cesium-rich rims, cesium-rich lepidolite and evolved Ta>Nb oxides (manganotantalite).

ALBITE-SPODUMENE LAYER (4)

The albite-spodumene layer in Trench SA-3 is characterized by coarse-grained spodumene, albite, quartz and beryl. The green spodumene has moderate iron contents (Fe_2O_3 = 0.61 to 0.86 weight %). The beryl, commonly zoned with green cores and pink rims, has a wide range in compositions (*see* Figure 16: Cs_2O = 0.22 to 4.38 weight %, Na_2O = 0.95 to 1.68 weight %).

The mica in the albite-spodumene layer has 3 compositions:

- Cs_2O-poor lepidolite
- Cs_2O-rich muscovite
- Cs_2O-rich lepidolite

All 3 types of mica exhibit a similar enrichment pattern of FeO (1.93 to 3.75 weight %) and Rb_2O (0.89 to 1.61 weight %). The cesium-poor lepidolite contains 0.05 to 0.08 weight % Cs_2O, the cesium-rich lepidolite contains 0.66 to 0.89 weight % Cs_2O, and the cesium-rich muscovite contains 0.37 to 0.89 weight % Cs_2O. The accessory potassium feldspar in the albite-spodumene zone is Rb_2O rich (1.34 to 1.52 weight %) and Cs_2O rich (0.17 to 0.30 weight %).

The accessory Ta-Nb oxide minerals in the albite-spodumene layer (4) are mostly manganotantalite with weak oscillatory or no zoning, but some of the manganotantalite contains manganocolumbite patches (*see* Figure 17). The oxide minerals have range in Ta_2O_5 from 25.78 to 75.64 weight % and exhibit highly evolved Mn/(Mn+Fe) ratios (0.83 to 0.94) and constitute the most tantalum- and manganese-rich oxide minerals in the South Aubry pegmatite. Poorly evolved manganocolumbite grains (Ta_2O_5 = 29.82 to 31.94 weight %) that reveal iron enrichment and a Mn/(Mn+Fe) = 0.62 to 0.75 are found in 02-JBS-26-1B.

Primary, euhedral grains of orange-brown microlite with Ta_2O_5 = 73.76 to 75.04 weight % and UO_2 = 0.37 to 0.45 weight % were found at 02-JBS-26-09 (Photo 22). Secondary microlite also is evident as a replacement in patchy zoned manganocolumbite to manganotantalite. Fluorapatite (*see* Figure 15) contains moderate amounts of MnO (0.55 to 3.00 weight %) except for 02-JBS-26-14 with higher MnO (4.58 to 5.36 weight %).

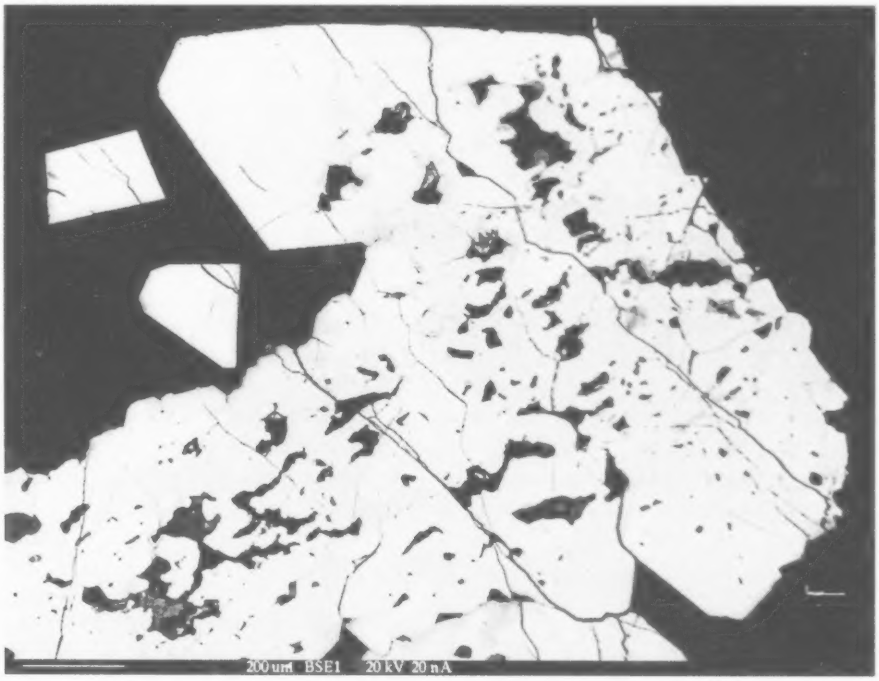

Photo 22. Primary euhedral aggregate of microlite (average Ta_2O_5 = 74.3 weight %) from the spodumene-rich layer, Trench SA-3.

POTASSIUM FELDSPAR AND MUSCOVITE BULK CHEMICAL VARIATION FOR AUBRY PEGMATITE SYSTEM

Bulk compositions of potassium feldspar and muscovite from the North and South Aubry pegmatites are summarized in Tables 6 and 7 and plotted in Figure 19. The Cs and Rb contents and the K/Rb ratio in potassium feldspar reveal a highly evolved pegmatite system that significantly falls largely within the field defined by the Bernic Lake pegmatite group of Manitoba (Černý et al. 1981, p.149). This field contains the Tanco pegmatite that exhibits potassium feldspar with the highest cesium and rubidium contents for the pegmatite group (Černý, Ercit and Vanstone 1996).

Bulk compositions of potassium feldspar from the North Aubry pegmatite (*see* Tindle, Selway and Breaks 2006 (MRD 210), Table 5; summarized in Table 6) indicate pronounced enrichment in Rb_2O (mean = 1.14; range 1.01 to 1.23 weight %) and Cs_2O (mean = 0.06; range 0.03 to 0.12 weight %), which indicates the highly evolved nature of the pegmatite (Tindle, Selway and Breaks 2002). The South Aubry pegmatite reveals a similar degree of evolution as marked by an overlap in Rb_2O (mean = 1.01; range = 0.70 to 1.32 weight %) and Cs_2O (mean = 0.09; range = 0.035 to 0.18 weight %) contents (*see* Tindle, Selway and Breaks 2006 (MRD 210), Table 5).

The very low, overall mean K/Rb (10.6) and K/Cs (mean = 225) ratios in the potassium feldspar compare from the North Aubry pegmatite system are similar to other complex-type pegmatites in the Superior Province of Ontario (Breaks, Selway and Tindle 2005).

The greatest degree of magmatic evolution in the entire Aubry pegmatite system is evident in Trench NA-5 and connector Trench NA-5-6 at the North Aubry pegmatite. Here, Rb_2O and Cs_2O contents in potassium feldspar attain maxima of 2.80 and 0.23 weight %, respectively (*see* Table 6).

In the South Aubry pegmatite, Rb_2O and Cs_2O levels respectively reach 1.33 and 0.16 weight % in Trench SA-3 (*see* Table 6). However, an overlap of compositions of the North and South Aubry pegmatites (*see* Figure 19) supports a common origin for these pegmatites.

Muscovite chemical data for the Aubry pegmatite system (Figure 20) define a tight cluster for cesium versus tantalum that overlaps with the field of highly evolved, complex-type, petalite-subtype pegmatites of the Separation Rapids pegmatite group (Selway, Breaks and Tindle 2006). All tantalum levels ($mean_{15}$ = 158 ppm Ta; range: 122 to 234 ppm Ta) are significantly above the 65 to 70 ppm Ta range of Morteani and Gaupp (1989), that signifies high potential for evolved Ta>Nb-bearing oxide minerals in the pegmatite system.

These tantalum values are comparable to those found in muscovite from the Tanco pegmatite (Morteani and Gaupp 1989; Černý, Ercit and Vanstone 1996), however, cesium contents in muscovite from the Aubry pegmatite system are lower ($mean_{15}$ = 614 ppm Cs; range: 525 to 871 ppm Cs). The highest tantalum level in muscovite from the Aubry pegmatite system was documented in Trench SA-3 of the South Aubry pegmatite (*see* Table 7: range = 184 to 234 ppm Ta).

Table 6. Mean and range of rubidium, cesium and K/Rb in potassium feldspar bulk compositions from the North and South Aubry pegmatites.

Pegmatite	Trench	Mean Rb (ppm)	Range Rb (ppm)	Mean Cs (ppm)	Range Cs (ppm)	Mean K/Rb	Range K/Rb
North Aubry	NA-1	10 900	10 688–11 316	516	427–567	10.0	9.2–10.6
	NA-2-3	10 132	9165–10 773	761	738–782	10.9	10.3–11.9
	NA-3	9701	9063–11 267	571	413–1125	11.3	9.7–13.0
	NA-4	9416	9204–9627	357	312–401	11.53	11.52–11.55
	NA-5	17 748	12 855–25 550	1710	1371–2152	6.4	4.4–8.1
	NA-5-6[1]	16 147		2009		6.8	
	NA-6	11 192	10 485–12 767	790	727–882	9.8	8.7–10.3
	SA-5	9796	9105–10 486	690	479–901	11.5	10.8–12.2
South Aubry	SA-1[1]	6898		511		16.1	
	SA-2[1]	8098		849		13.9	
	SA-3	11 865	11 671–12 060	1542	1322–1763	9.5	9.4–9.6

[1] analysis of one sample only

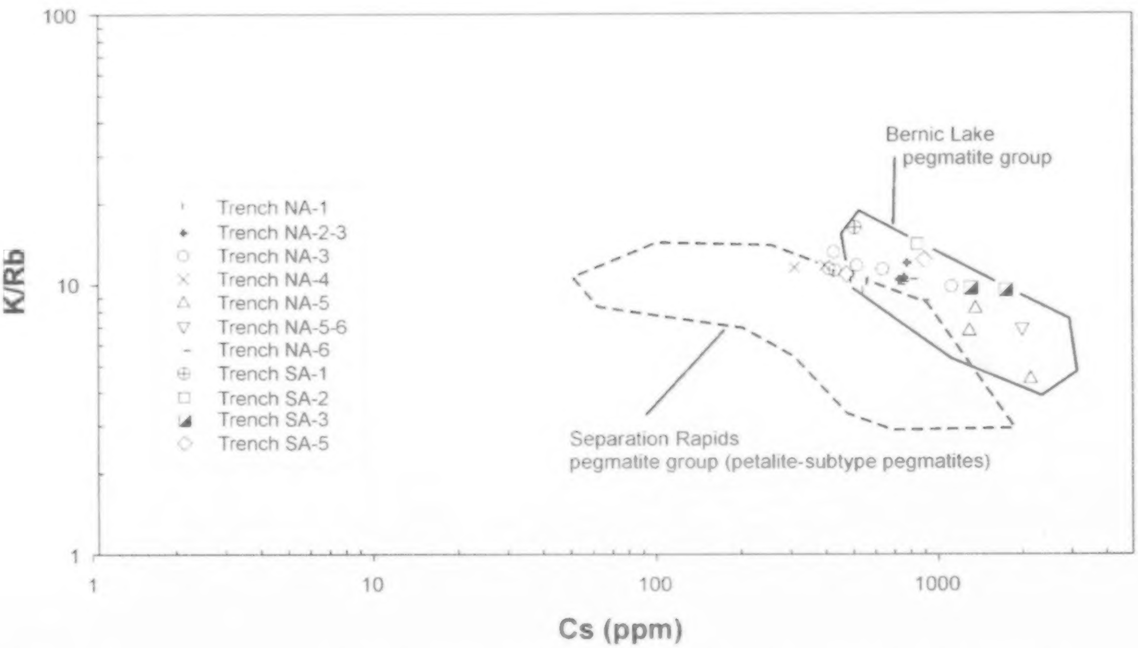

Figure 19. Cesium (ppm) versus K/Rb in bulk samples of potassium feldspar from the North and South Aubry pegmatites. Fields of variation for the Separation Rapids pegmatite group and the Bernic Lake pegmatite group, respectively, *after* Breaks, Tindle and Smith (1999) and Černý et al. (1981).

Table 7. Rare-element content and selected element ratios in muscovite bulk compositions from the Armstrong pegmatite field.

Location	Be (ppm)	Cs (ppm)	Li (ppm)	Nb (ppm)	Rb (ppm)	Sn (ppm)	Ta (ppm)	K/Cs	K/Rb	Nb/Ta
North Aubry Pegmatite										
Trench NA-1	16	252	3118	190	12 436	252	149	158	6.7	1.3
Trench NA-2	19	871	3647	187	12 278	230	159	95	6.7	1.2
Trench NA 2-3	19	717	2000	147	15 888	253	137	113	5.1	1.1
Trench NA-3	18	561	2337	140	12 109	177	129	147	6.8	1.1
Trench NA-5	18	692	1060	108	15 496	277	138	113	5.0	0.8
Trench NA-5	17	619	3000	240	12 239	219	129	135	6.9	1.9
Trench NA-5-6	18	547	2160	201	11 273	242	131	151	7.3	1.5
Trench NA-5-6	19	735	2068	136	14 871	247	140	110	5.4	1.0
Trench NA-6	17	566	2843	249	11 424	263	141	147	7.3	1.8
Trench NA-6	16	590	4349	341	12 361	320	145	141	6.7	2.4
Trench NA-6	16	543	4761	316	10 519	341	165	155	8.0	1.9
Mean	17.5	608	2849	205	12 808	256	142	133	6.5	1.5
South Aubry Pegmatite										
Trench SA-1	22	525	6940	386	10 921	208	184	164	7.9	2.1
Trench SA-1	19	583	5870	351	11 286	210	234	187	9.7	1.5
Trench SA-2	17	567	6990	448	11 688	235	200	515	7.3	2.2
Trench SA-3	14	578	6350	388	11 464	173	184	145	7.4	2.1
Mean	18	563	6538	393	11 339	207	201	253	8.1	2.0
English River Subprovince: barren peraluminous, pegmatitic granite										
02-JBS-46-05	2	15	36	50	415	25	4.1	5954	215	12.2
North Jackfish Road muscovite pegmatite										
02-FWB-40-03	10	87	252	3618	371	370	122	987	24	3.0
Ketchican Road beryl-type pegmatite										
02-FWB-41-02	10	213	324	485	4381	591	147	408	20	9.1
Abamasagi Lake Road beryl-type pegmatite										
02-FWB-54-02	23	241	969	263	1991	116	63	356	43	4.2
Maytham–Queenston lakes pegmatitic granite										
02-FWB-56-01	3	13	153	67	501	21	5	6730	174	12.9

Notes:

02-JBS-46-05: Silver muscovite from quartz vein in garnet-biotite pegmatitic leucogranite
02-FWB-40-03: Silver muscovite from apatite-garnet-muscovite pegmatite
02-FWB-41-02: Silver muscovite from beryl-garnet-biotite-muscovite pegmatite
02-FWB-54-02: Silver muscovite selected near blocky potassium feldspar-quartz-rich patch in garnet-biotite-muscovite pegmatitic leucogranite
02-FWB-56-01: Silver muscovite from garnet-muscovite potassic pegmatite

Petrogenesis of North and South Aubry Pegmatite

There are many similarities between the style of intrusion and the mineralogy of North and South Aubry pegmatites that infer a common pegmatite system:

- proximal location (approximately 185 m apart assuming that the pegmatite exposed in Trench SA-5 comprises part of the North Aubry pegmatite)
- both pegmatites consist of stacked sheets that dip shallowly to steeply to the east
- both comprise spodumene-subtype pegmatites that inflicted rare-element-enriched metasomatism in mafic metavolcanic host rocks
- Ta-Nb oxide phases exhibit a similar range: manganocolumbite and manganotantalite in South Aubry pegmatite (beryl-spodumene and albite-spodumene zones) resemble those in some zones of the North Aubry pegmatite (albite-spodumene and potassium feldspar-spodumene zones)
- beryl compositions of both pegmatites overlap in the Na_2O versus Cs_2O diagram
- potassium feldspar and muscovite compositions overlap in cesium versus K/Rb and cesium versus tantalum diagrams that supports a genetic relationship
- fluorapatite from the albite-spodumene zone of the North Aubry pegmatite spans the compositional gap between the MnO-poor and MnO-rich fluorapatite in the albite-spodumene layer of the South Aubry pegmatite

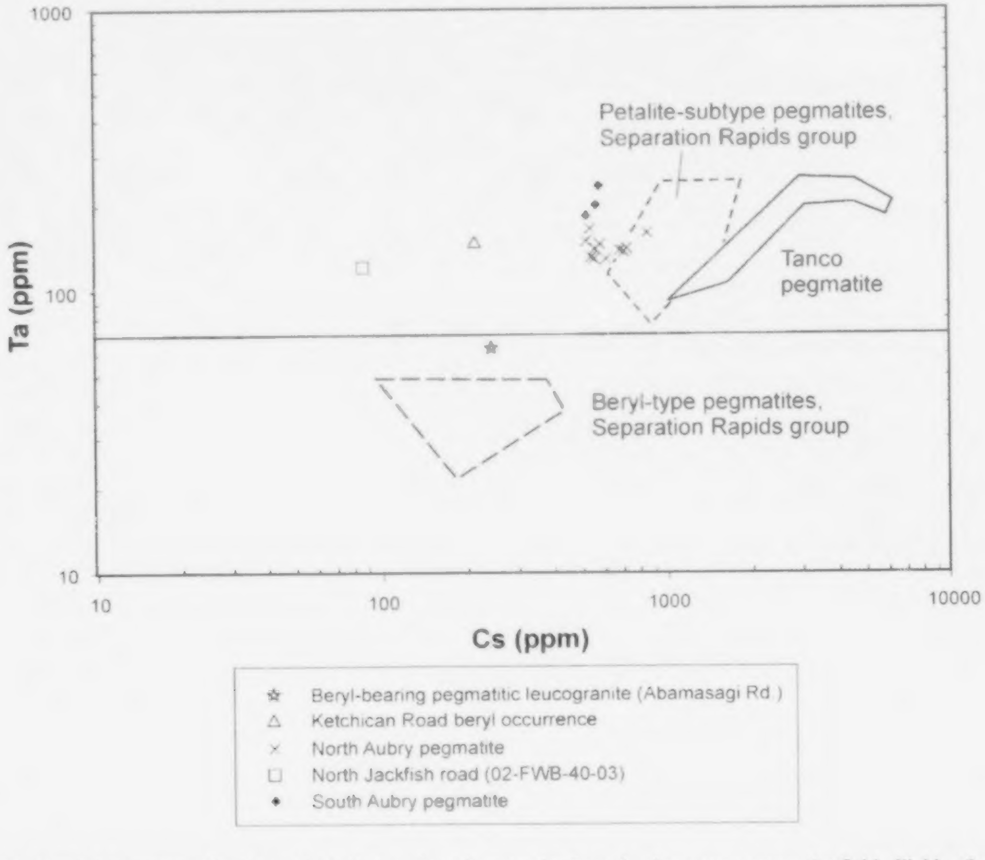

Figure 20. Cesium versus tantalum (ppm) in bulk samples of muscovite from the Armstrong pegmatite field. Fields of variation for the Separation Rapids pegmatite group (beryl-type and petalite-subtype) from unpublished data of the authors. The Tanco pegmatite field is *from* Morteani and Gaupp (1989).

The following zones from the North and South Aubry pegmatites are interpreted as products of a similar fractionation history:

- aplite border (South Aubry zone 1) and outer sodic aplite zone (North Aubry zone 2)
- plumose muscovite zone and plumose muscovite layer (South Aubry zone 2) and quartz-muscovite zone (North Aubry zone 3)
- beryl-spodumene zone and the albite-spodumene layer (South Aubry zones 3 and 4) and the albite-spodumene zone (North Aubry zone 7)

The absence of petalite and spodumene-quartz intergrowths after petalite in the Aubry pegmatite system indicates crystallization at pressures greater than 2 kilobars and at moderate temperatures (London 1984). Potassium feldspar is the most abundant potassium mineral in North Aubry, whereas muscovite is dominates in the South Aubry pegmatite. The North Aubry pegmatite has albite-rich outer zones, potassium feldspar- and spodumene-rich intermediate zones and an albite- and spodumene-rich core zone.

The South Aubry pegmatite has an albite-rich outer zone, muscovite- and albite-rich intermediate zone (plumose muscovite) and albite- and spodumene-rich innermost zone. Both pegmatite melts evolve in composition from sodium rich to potassium rich to (Na, Li)-rich. The abundance of spodumene and potassium feldspar, common muscovite and rare lepidolite in the North Aubry pegmatite indicates that the granitic melt had low acidity and a wide range in salinity (London 1982). Similarly, the abundance of spodumene and muscovite in the South Aubry pegmatite indicates that the granitic melt had low acidity and low salinity (London 1982). The abundance of coarse-grained muscovite throughout both pegmatites indicates that the melt was strongly peraluminous and had elevated H_2O contents relative to granitic melts that are barren of muscovite (Kerrick 1972). The fluorine content in the melt was likely elevated, now indicated by the widespread accessory fluorapatite and to sparser lepidolite and microlite. The boron content in the melt was likely low as indicated by the scarcity of tourmaline in the outer sodic zones of both pegmatites and its absence in the rest of the pegmatite zones.

The intrusion of the pegmatite-forming melt for both pegmatites was accompanied by metasomatism of the mafic metavolcanic host rocks. A migration of potassium- and rare-element-rich fluids (Li, Rb, Cs) and local boron into the host rocks resulted in the formation of ubiquitous siderophyllite-zinnwaldite and along the pegmatite contacts, but holmquistite and tourmaline (calcium-rich dravite-schorl) are only localized (e.g., Trench NA-5 of the North Aubry pegmatite). The rare calcium-bearing schorl-dravite and abundant siderophyllite-zinnwaldite in the outer sodic aplite zones suggests host rock interaction of pegmatite-forming fluids that scavenged calcium, magnesium and iron from the host rocks (especially calc-silicate segregations) or derived xenoliths.

The proximity, similar mineralogy and inferred crystallization conditions suggests a genetic relationship between the North and South Aubry pegmatites. If the 2 pegmatites are genetically related, it follows that the entire pegmatite system could involve a strike-length of approximately 1 km long. Furthermore, there exists an exploration potential for tantalum-rich manganotantalite, as documented in Trench NA-5, elsewhere along the projected strike-length of the pegmatite system to the south.

Most of the interior pegmatite zones are interpreted to have crystallized from an relatively uncontaminated pegmatite melt that increased in fractionation from the outer sodic aplite zone to the inner core zone. With increasing fractionation, the melt became more enriched in volatiles, rare-elements (tantalum, lithium, cesium, rubidium) and MnO. The inner core zone indicates the highest degree of pegmatite evolution and contains abundant spodumene, coarse-grained manganotantalite and cesium-rich pink beryl and accessory manganese-rich fluorapatite, altered pollucite, rubidium- and cesium-rich potassium feldspar and muscovite.

South Aubry Lepidolite Boulder

The South Aubry lepidolite boulder (Photo 23), found in Trench SA-4 by Linear Resources Inc. (UTM 396795E 5584287N, Zone 16) is located approximately 200 m south of the South Aubry pegmatite. The mineralogy of this 50 by 53 by 60 cm angular boulder indicates a probable derivation from outside the immediate area (i.e., North Aubry and South Aubry pegmatites and Swole Lake pegmatite boulder field) owing to its distinctive mineralogy. In hand sample, the boulder dominantly consists of purple mica with abundant fresh grey spodumene locally altered to a green colouration, quartz and aplite patches. A detailed microprobe examination of samples from this boulder revealed wodginite and montebrasite that are not found in the nearby *in-situ* pegmatites.

Pollucite [$(Cs,Na)AlSi_2O_6{\cdot}nH_2O$] occurs as a late phase distributed along cleavages and partings in spodumene (Photo 24a). Four electron microprobe compositions gave a range of 25.0 to 34.0 weight % Cs_2O). This mineral is rare in the Armstrong pegmatite field and is only known elsewhere at Trench NA-5 of the North Aubry pegmatite.

The following tantalum-oxide minerals were identified in the lepidolite boulder:

- manganotantalite
- wodginite [$Mn(Sn,Ta)Ta_2O_8$]
- uranium-rich microlite [$(Ca,U)_2Ta_2O_6(OH,F)$]
- cassiterite (0.71 weight % Ta_2O_5).

The manganotantalite (Photo 24b) contains elevated tantalum contents similar to that found in North Aubry Trench NA-5 (compare Figures 5 and 21) and comparable to manganotantalite from the Central Intermediate Zone (6) of the Tanco pegmatite, southeastern Manitoba (Černý, Ercit and Vanstone 1996). The manganotantalite grains are typically less than 50 µm in length and relatively uncommon with an average of 81.12 weight % Ta_2O_5.

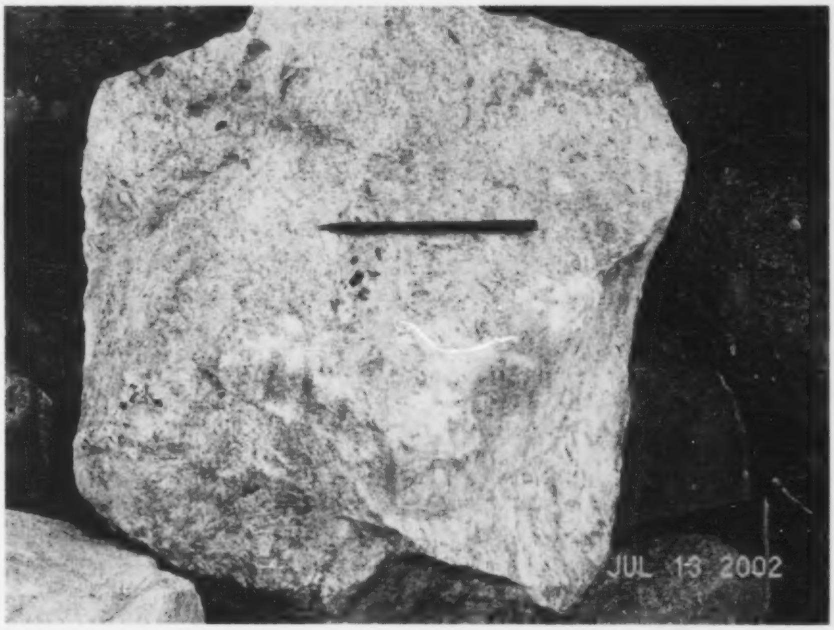

Photo 23. View of spodumene-beryl-lepidolite-quartz-albite boulder in Trench SA-4.

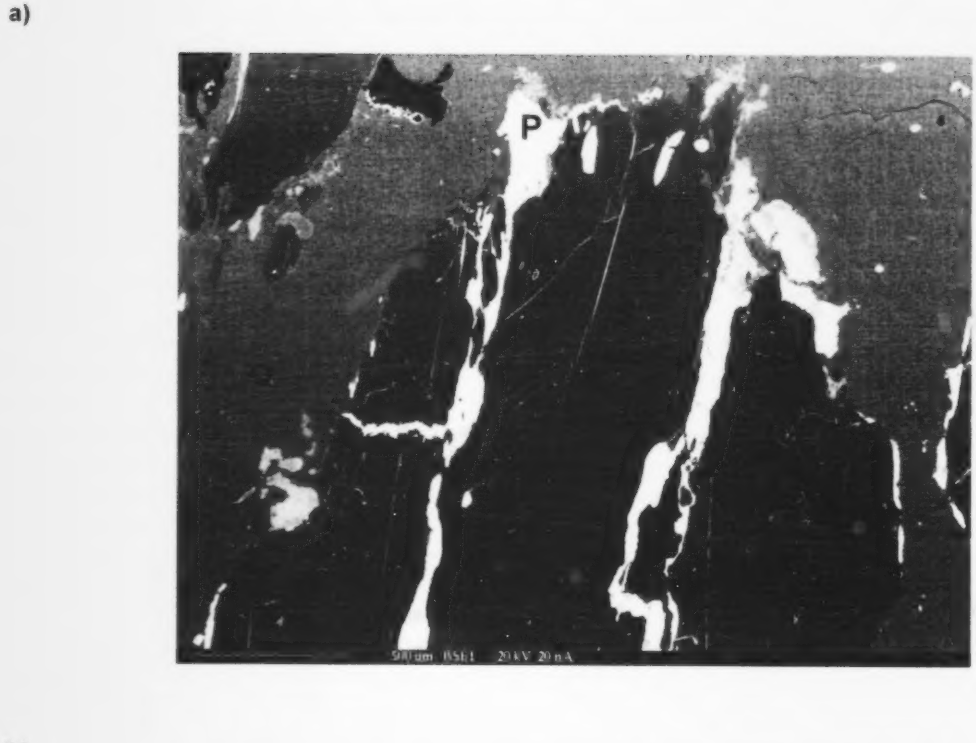
a)
P
500 um BSE1 20 kV 20 nA
b)
Manganotantalite
Manganotantalite = 78.3 - 82.0 wt.% Ta2O5
Wodginite = 68.2 wt.% Ta2O5
Wodginite
50 um BSE1 20 kV 20 nA

Photo 24. a) Pollucite (P) distributed along veins, partings and crystal surfaces of spodumene (S) enveloped by quartz (Q). b) Crystal fragments of manganotantalite and wodginite from the lepidolite boulder (Trench SA-4).

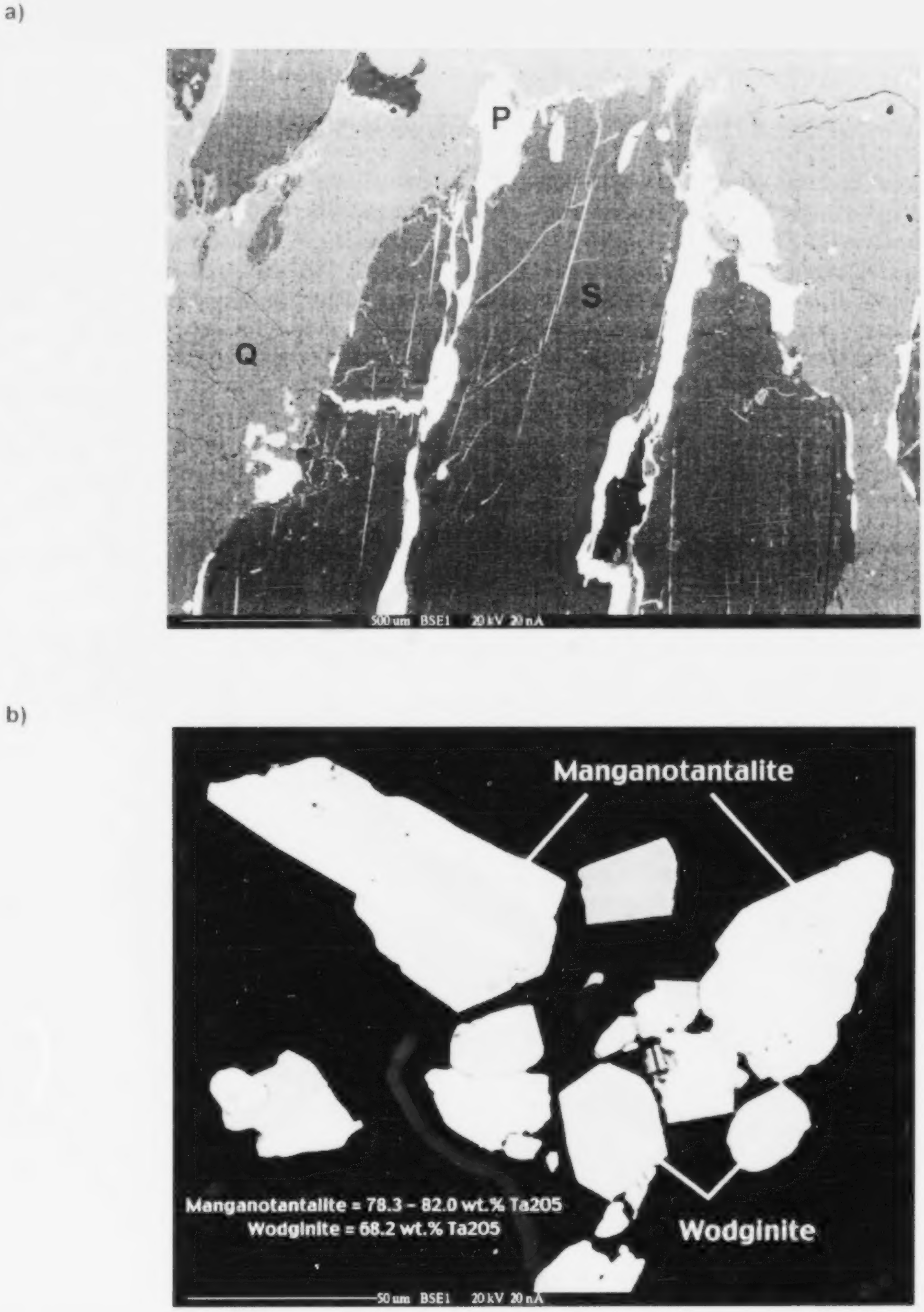
a)
P
S
Q
500 um BSE1 20 kV 20 nA
b)
Manganotantalite
Manganotantalite = 78.3 – 82.0 wt.% Ta205
Wodginite = 68.2 wt.% Ta205
Wodginite
50 um BSE1 20 kV 20 nA

Photo 24. a) Pollucite (P) distributed along veins, partings and crystal surfaces of spodumene (S) enveloped by quartz (Q). b) Crystal fragments of manganotantalite and wodginite from the lepidolite boulder (Trench SA-4).

Wodginite (*see* Photo 24b), associated with the manganotantalite, occurs as grains up to 40 μm diameter and has an average Ta_2O_5 of 69.30 weight %. The presence of wodginite in this boulder is significant, as wodginite is the main tantalum ore mineral in the Tanco pegmatite mine and has only been documented in 3 other pegmatite groups in Ontario (Breaks, Selway and Tindle 2005). The uranium-rich microlite contains an average of 72.62 weight % Ta_2O_5 and 6.60 weight % UO_2.

The lithium-rich minerals in the lepidolite boulder consist of abundant spodumene, montebrasite [$LiAl(PO_4)(OH,F)$] and minor lepidolite. In hand sample, lepidolite appears to be abundant, but actually most of the mica is muscovite partially replaced by lepidolite rims. The average rubidium and cesium contents are elevated in the lepidolite rims (Rb_2O = 4.3 weight %, Cs_2O = 0.82 weight %) relative to the muscovite cores (Rb_2O = 2.7 weight %, Cs_2O = 0.36 weight %). Montebrasite, more abundant than fluorapatite in the boulder, is not known to occur in other pegmatites of the Armstrong field. In the Superior Province of Ontario, montebrasite has only been documented at Pakeagama Lake (Tindle, Breaks and Selway 2002).

Cesium-rich beryl was identified in one euhedral grain of beryl (310 μm across) that is zoned with "filaments" with elevated cesium. Beryl has an average Cs_2O content of 3.2 weight % with the highest values occurring in the rim. This value is comparable to the Cs_2O enrichment that characterizes beryl from zones 6 and 9 of the Tanco pegmatite (Černý, Ercit and Vanstone 1996: 2.47 to 3.27 weight % Cs_2O).

The presence of pollucite, tantalum-rich manganotantalite, wodginite, microlite and montebrasite indicates that this boulder was derived from a highly fractionated, complex-type pegmatite. The round shape of this boulder coupled with its unique mineral assemblage *vis-a-vis* the North and South Aubry pegmatites, implies a source beyond the Seymour Lake pegmatite group. Pegmatites of a similar degree of evolution are found in the Swole Lake boulder field that may have a common source with the South Aubry lepidolite boulder although a striking similarity is with the Pakeagama Lake pegmatite (Tindle, Breaks and Selway 2002; Breaks, Selway and Tindle 2005).

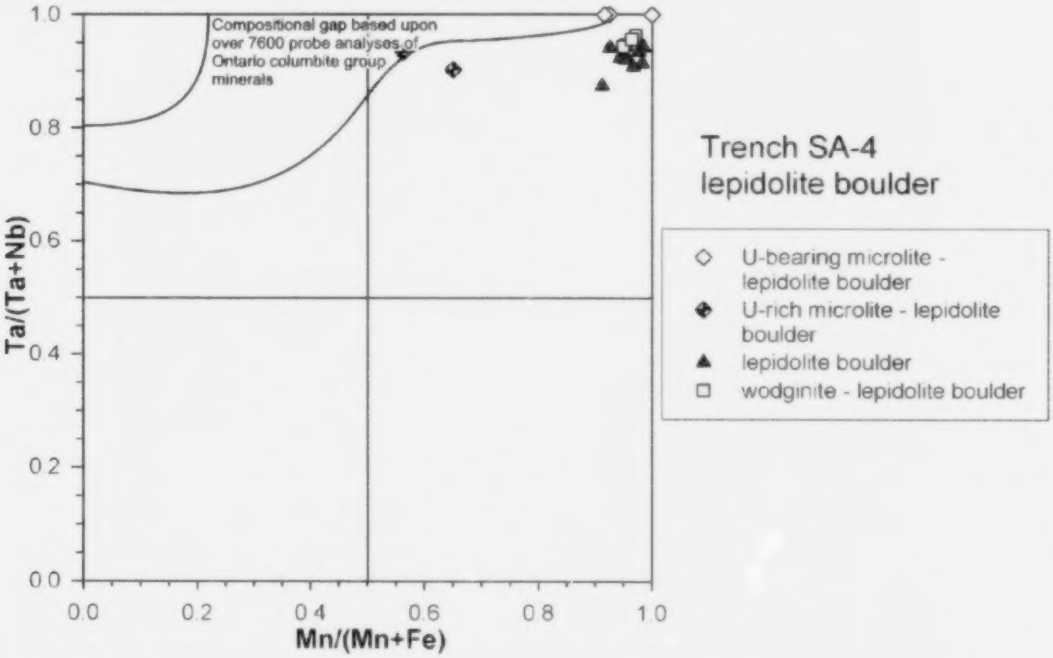

Figure 21. Columbite-tantalite quadrilateral plot (atomic ratios) for the lepidolite boulder, Trench SA-4 in South Aubry pegmatite. Compositional gap between ferrotapiolite and ferrotantalite is based upon 7600 compositions of columbite-tantalite from Ontario. Microlite compositions may plot within this compositional space.

SWOLE LAKE PEGMATITE

The Swole Lake pegmatite boulder field (*see* Figures 2 and 3 (back pocket)) represents a new rare-element discovery in the Armstrong pegmatite field that was found by prospectors M. and S. Stares of Thunder Bay. The locality comprises a 60 by 100 m boulder field near the western shoreline of Swole Lake (*see* Figure 3, back pocket), in which a high percentage of angular boulders consist of lepidolite-spodumene pegmatite. The pegmatite boulders are characterized by abundant lepidolite and cleavelandite, altered spodumene mantled by lepidolite and albitized potassium feldspar. Spectacularly zoned manganotantalite crystals were observed in earlier samples provided by the Stares Brothers in 2001 (Photo 25).

The origin of the local concentration of large, angular, rare-element-mineralized boulders is uncertain, but may represent either frost-heaving from the actual pegmatite at subsurface or short distance ice transport. The host rock is a fine-grained, foliated, unmigmatized metawacke with 1 to 2 volume % of quartz up to 3 mm in diameter.

Several pegmatite boulders were examined and sampled in detail. At 02-JBS-18 (UTM 433157E 5588229N, Zone 16) is a 0.9 by 2.1 m boulder with a minimum thickness of 0.7 m. The pegmatite contains abundant altered spodumene, lepidolite, cleavelandite, pink, albitized, blocky potassium feldspar, quartz, minor, 1 mm by 1 cm, blades of manganotantalite and rare blue fluorapatite. The fresh spodumene is faint green to pale pink and white and is locally oriented perpendicular to the host rock contact. The spodumene occurs as pervasively altered pseudomorphs composed of fine-grained secondary lepidolite. Spodumene is also altered to dark green chlorite and red hematite. Relict cores of spodumene are locally apparent.

The boulder at 02-JBS-19 (UTM 433155E 5586193N, Zone 16) is 2 by 2.5 m with a minimum depth of 1.5 m. Internal zoning is subtly evident as a 1 cm thick aplite border zone, similar to that at 02-JBS-18 (Photo 26). The metasedimentary host rock, 40 cm from the contact with the pegmatite, reveals fine-grained quartz, coarse-grained hornblende, sericitized feldspar and minor epidote and chlorite. The host rock contains a layer of biotite, quartz and chlorite and is intruded by quartz veins. Concentration of "biotite" (siderophyllite-zinnwaldite) is evident along the host rock–pegmatite contact. The pegmatite at the contact contains strongly sericitized feldspar with quartz inclusions, whereas the pegmatite 4 mm from the contact contains unaltered albite, quartz and muscovite. These observations infer the host rock–pegmatite contact was a locus for potassium-rich metasomatic fluids that generated a biotite-rich aureole within the host rock and altered the feldspar to sericite within the pegmatite.

A third boulder at 02-JBS-22 (UTM 433170E 5586171N, Zone 16) exposes part of an extensive holmquistite alteration zone, at least 75 cm wide, developed in a quartz-feldspar porphyry in contact with pegmatite. The latter contains cleavelandite, quartz and minor spessartine and pyrite. Holmquistite is a lithium-amphibole that specifically occurs in metasomatized host rocks adjacent to lithium-rich pegmatites and has been utilized as an indicator mineral in the exploration for unexposed rare-element pegmatites (Breaks, Selway and Tindle 2003a, p.16-17).

Petrochemistry of the Swole Lake Pegmatite

Bulk rock analyses of the pegmatite (*see* Tindle, Selway and Breaks 2006 (MRD 210), Table 4), relative to the average upper continental crust, reveal elevated Na_2O contents (7.56 weight %) and $Na_2O >> K_2O$ due to the abundance of cleavelandite; elevated lithium (615 ppm), rubidium (843 ppm) and cesium (49 ppm) due to lepidolite; elevated beryllium (272 ppm) due to liberite (Li_2BeSiO_4) and possible fine-grained unobserved beryl; elevated niobium (77 ppm), tantalum (337 ppm) and low Nb/Ta ratio (0.2) due to manganotantalite.

The bulk rock composition of the holmquistite-altered, quartz-plagioclase porphyry is chemically less evolved than the pegmatite as mainly indicated by higher Fe_2O_3 (4.14 weight %) and MgO (2.37 weight %) due to abundant holmquistite.

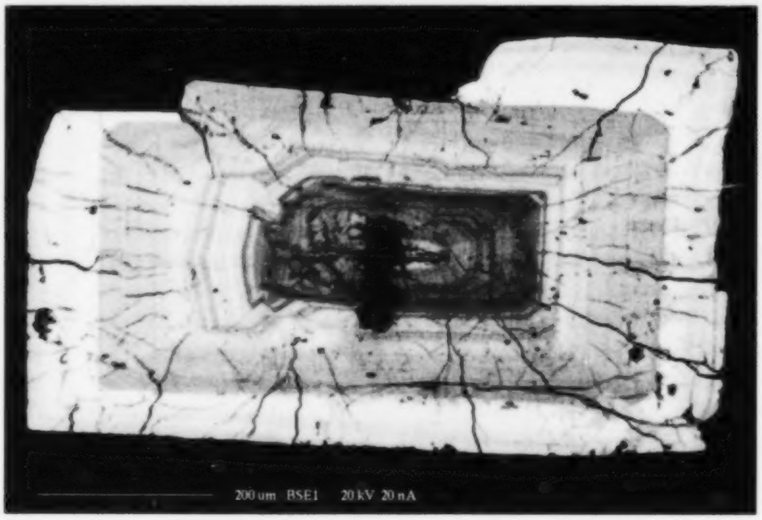

Photo 25. Spectacular oscillatory zonation in a manganotantalite crystal from the Swole Lake pegmatite boulder field that exhibits increasing Ta_2O_5 from the core (53.22 weight %) to the rim (84.53 weight %). Dark area represents a hole in the polished grain mount.

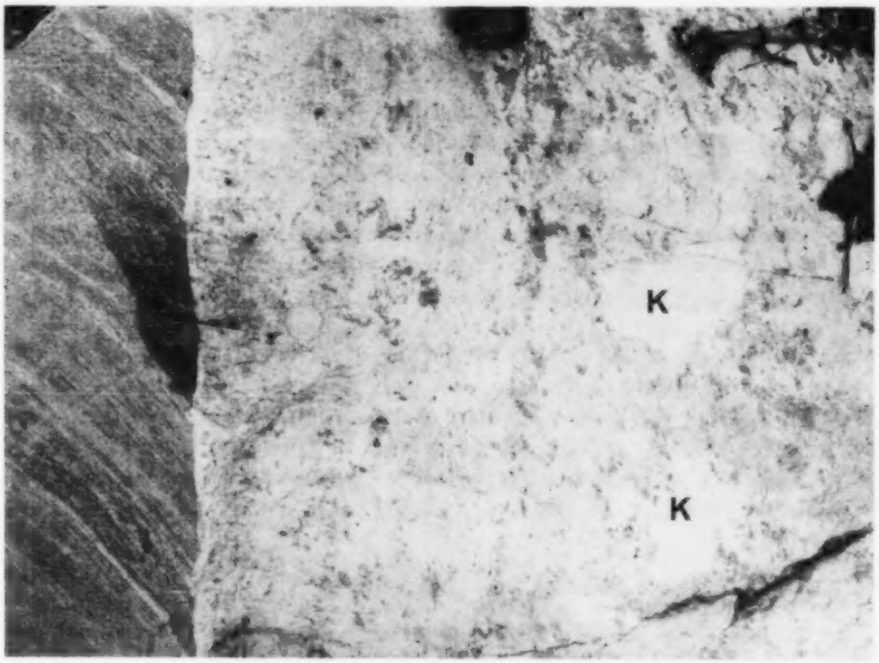

Photo 26. Discordant contact between foliated metawacke and vaguely zoned spodumene-lepidolite-quartz-albite pegmatite boulder field at Swole Lake. Note the thin quartz-albite border zone and adjacent megacrysts of albitized blocky potassium feldspar (K).

Mineral Chemistry of the Swole Lake Pegmatite

The manganotantalite forms euhedral, bladed crystals up to 1 cm in length and is characterized by concentric zonation. Some of this zonation is oscillatory, and the dominant trend is from a tantalum-poor core to a tantalum-rich rim. One sample contains zoned oxides with manganocolumbite cores and manganotantalite rims. The composition of the manganotantalite (average Mn/(Mn+Fe) = 0.99 and range 0.90 to 1.00) from the Swole Lake pegmatite boulders is unique in Ontario due to the exceptionally low iron content that results in the data strongly clustered along the right-hand margin of the columbite-tantalite quadrilateral (Figure 22).

The manganotantalite also has a high tantalum content (average Ta_2O_5 of 71.06 weight %; range: 42.13 to 86.56 weight %). Some manganotantalite grains have radial fractures likely of metamict origin due to a small to significant uranium content. Most of the compositions reveal uranium contents below the probe detection limit (estimated to be 0.02 weight % UO_2), but UO_2 reaches a maximum of 0.55 weight % in the core of one grain.

The quartz-albite unit, 10 cm from the contact with the metasedimentary host rock (02-JBS-21-02), contains tantalian rutile and microlite. The tantalian rutile (Ta_2O_5 = 43 to 47 weight % and TiO_2 = 33 to 41 weight %) occurs as a relict core in a patchy zoned manganotantalite grain.

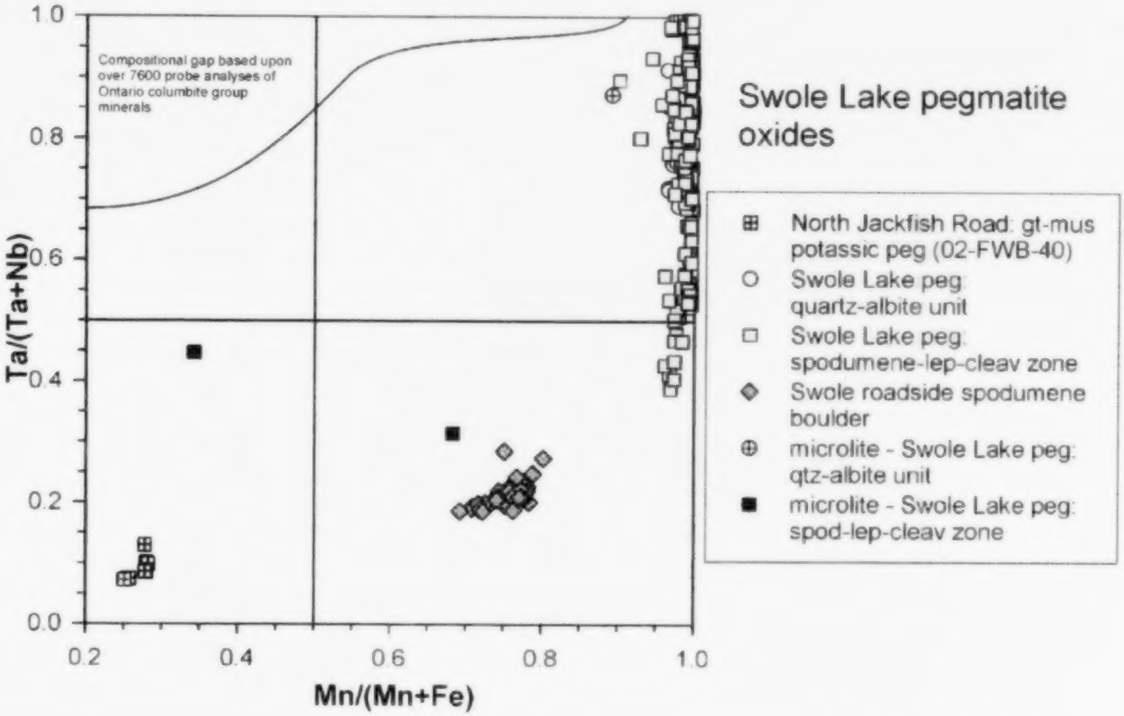

Figure 22. Columbite-tantalite quadrilateral plot (atomic ratios) for lepidolite-subtype pegmatite from the Swole Lake boulder field. Compositional gap between ferrotapiolite and ferrotantalite is based upon 7600 compositions of columbite-tantalite from Ontario. Microlite compositions may plot within this compositional space.

There is some evidence that late replacement of manganotantalite by microlite as several manganotantalite compositions contain a small calcium content. It was not possible to generate data from microlite itself, due to its rarity, high degree of alteration and intergrowth with manganotantalite. The presence of iron-free manganotantalite and microlite with elevated tantalum contents indicate that the oxide minerals crystallized from a fractionated pegmatite melt that was not noticeably contaminated by interaction of its fluids with the host rocks. However, the replacement of manganotantalite by microlite indicates the intervention of late-stage fluids, probably of magmatic origin.

In addition to the manganotantalite being manganese rich, the garnet, fluorapatite and lepidolite are also manganese rich. Garnet is rare and contains 78 to 94% spessartine. Blue fluorapatite has an average and range in MnO of 5.05 weight % and 0.83 to 10.18 weight %. Lepidolite is manganese, rubidium and cesium rich with an average MnO = 2.32 weight %, Rb_2O = 0.80 weight % and Cs_2O = 0.20 weight %. Potassium feldspar is Rb_2O rich (0.32 to 0.69 weight %) and Cs_2O up to 0.08 weight %. Accessory minerals in the Swole Lake pegmatite are also fluorine rich: lepidolite, fluorite, fluorapatite and microlite. Rare needles of liberite (Li_2BeSiO_4) are associated with fluorite and quartz (Photo 27).

The Swole Lake pegmatite is lepidolite-subtype, even though lepidolite appears to be predominantly secondary in origin, because it exhibits several characteristics of lepidolite-subtype pegmatites as defined by Černý (1989):

- albite (cleavelandite and aplite) >> potassium feldspar in the main pegmatite mineral assemblage and Na_2O >> K_2O in bulk whole rock sample
- manganese-rich accessory mineralogy: manganotantalite, spessartine, fluorapatite and lepidolite
- fluorine-rich accessory minerals: lepidolite, fluorite, fluorapatite and microlite
- highly evolved manganotantalite with Mn/(Mn+Fe) ratios greater than 0.9. The mean Mn/(Mn+Fe) ratio in the Swole Lake pegmatite boulders is 0.99.

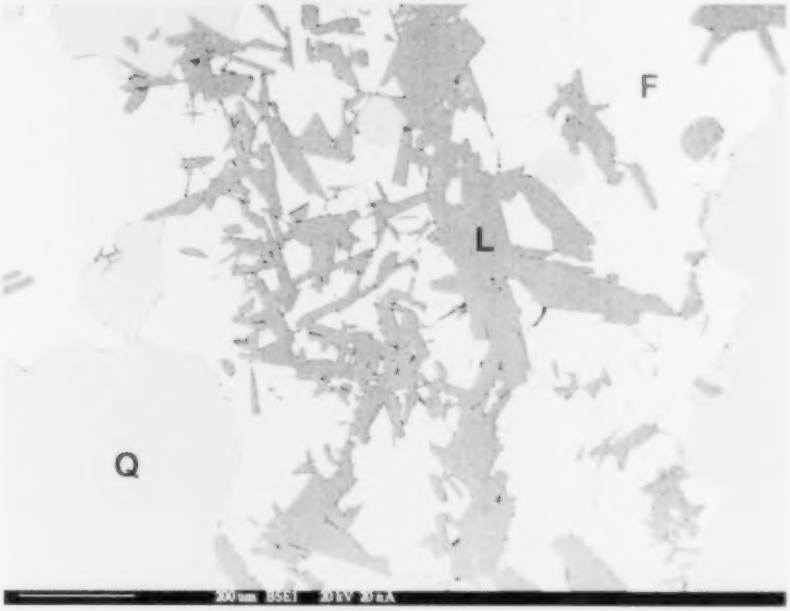

Photo 27. Needles of liberite (L) intergrown with fluorite (F) and quartz (Q) at 02-JBS-19-10 of the Swole Lake pegmatite boulder field.

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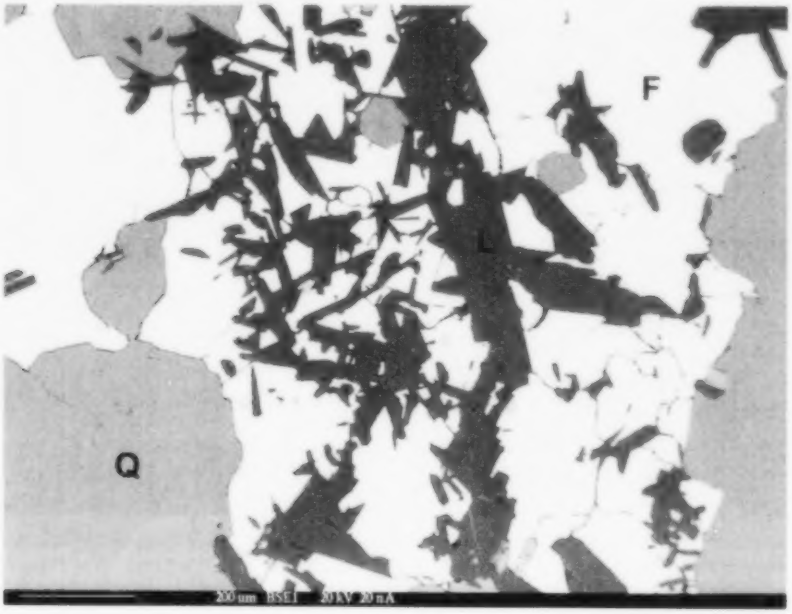


Photo 27. Needles of liberite (L) intergrown with fluorite (F) and quartz (Q) at 02-JBS-19-10 of the Swole Lake pegmatite boulder field.

Swole Lake Roadside Spodumene Boulder

A large spodumene boulder was collected on the Jackfish Road south of Swole Lake (02-JBS-23: UTM 432686E 5584367N, Zone 16) and completely removed from the site for laboratory investigation. The boulder, discovered by M. and S. Stares, consists of abundant, pale green, coarse-grained, bladed spodumene crystals, white, blocky potassium feldspar, yellow green muscovite, aplite patches and quartz. Accessory minerals include blue fluorapatite and Nb-Ta oxide minerals. Potassium feldspar megacrysts reveal local and mainly marginal albitization.

The oxides occur mostly in aplite patches, but are also associated with albitization of potassium feldspar and in quartz-rich patches. These consist of manganocolumbite with an average Ta_2O_5 of 25.1 weight % and range of 22 to 32 weight % that form a distinct cluster in Figure 22. The primary fluorapatite is generally more MnO rich (2.00 to 5.36 weight %) than the fluorapatite associated with albitized potassium feldspar (1.73 to 3.63 weight % MnO). The potassium feldspar is slightly enriched in rubidium with 0.26 to 0.30 weight % Rb_2O.

The mineralogy of the Swole Lake roadside boulder significantly differs from that of the Swole Lake pegmatite boulder field, the latter characterized by its more evolved Ta-Nb oxide minerals (manganotantalite and minor microlite). The chemical and mineralogical data support the interpretation of a different pegmatite source for this boulder and likely from a less evolved albite-spodumene-type pegmatite cluster perhaps located elsewhere in the Armstrong pegmatite field.

Ketchican Road Beryl Occurrence

Pale green beryl was discovered in a pale pink, 2 m wide dike of garnet-biotite-muscovite pegmatitic leucogranite near the south side of the Ketchican Lake Road (02-FWB-41: UTM 411242E 5586228N, Zone 16). The dike strikes about 010° with a steep undetermined dip to the west and is hosted in tonalitic rocks that comprise a large granitic terrane situated south of the Onaman–Tashota greenstone belt (*see* Figures 2 and 3 (back pocket)). The euhedral beryl crystals are mostly hosted within a 20 by 52 cm quartz-rich patch and have maximum dimensions of 2.3 by 2.7 cm and 3 by 5 cm, respectively, in sections normal and parallel to the c-axis. The leucogranite also contains blocky potassium feldspar up to 33 cm across, abundant muscovite and sparse garnet.

A muscovite bulk sample revealed anomalous levels of most rare-elements: Li (324 ppm), Cs (213 ppm), Sn (591 ppm), Nb (485 ppm), Ta (147 ppm) and evolved K/Rb (20) and Nb/Ta (3.3) ratios. In particular, the tantalum content of 147 ppm in muscovite from this beryl-type pegmatite is comparable with tantalum levels in muscovite (167 to 371 ppm) from the Aubry pegmatite system, although the Ketchican beryl-type pegmatite does not coincide with the main Aubry data cluster in the cesium versus tantalum diagram (*see* Figure 20), due to a lower cesium content.

A green beryl crystal (2.5 by 5 cm) in the albite-muscovite-quartz assemblage contains low Cs_2O (0.09 to 0.18 weight %) and Na_2O (0.44 to 0.73 weight %). The garnet is almandine rich (55 to 61% almandine, 37 to 43% spessartine).

This is a new occurrence beyond the known limits of the other pegmatite groups in the Seymour, Crescent and Falcon lakes area and, therefore, further prospecting within the tonalite-trondhjemite-granodiorite terrane south of the greenstone belt is encouraged as this beryl occurrence could be part of a larger, zoned, rare-element pegmatite dike swarm.

Rare-Element Dispersion in Mafic Metavolcanic Rocks, North Jackfish Road

Significant lithochemical dispersion was detected at 02-FWB-40 (UTM 411173E 5588515N, Zone 16) on the North Jackfish Road. This occurrence is situated along the eastern fringes of the Crescent Lake pegmatite group about 3 km southeast of the Dempster East spodumene pegmatite (*see* location 02-FWB-40 on Figure 3, back pocket; *see also* Pye 1965, p.58). As such, this occurrence may be connected to this pegmatite group and infer a much larger extent for potential rare-element mineralization as the area between the Dempster East pegmatite and this locality is mainly covered by surficial materials.

A white, weathered, 2 m thick pegmatite dike composed of apatite-garnet-muscovite-potassium feldspar-quartz-albite occurs within intermediate metavolcanic rocks. The pegmatite dike also contains quartz-muscovite segregations, up to 10 by 20 cm, white blocky potassium feldspar, yellow green muscovite and minor amounts of grey blue apatite, red garnet and sparse Ta-Nb oxides. A concentration of molybdenite grains, up to 1 cm diameter, is locally distributed along the eastern contact of the pegmatite.

A channel sample taken across 1 m of the pegmatite dike (*see* Tindle, Selway and Breaks 2006 (MRD 210), Table 4) revealed $Na_2O > K_2O$ (6.46 versus 3.48 weight %), generally low levels of rare-elements, but a modest fractionation as indicated by K/Rb ratio of 55. This degree of fractionation is comparable to various fertile granite units as documented elsewhere in the Superior Province (Breaks, Selway and Tindle 2003a).

The bulk composition of muscovite from the dike (*see* Tindle, Selway and Breaks 2006 (MRD 210), Table 5), however, revealed the notable rare-element enrichment, particularly by concentrations of Rb (3618 ppm), Nb (371 ppm), Sn (370 ppm) and Ta (122 ppm). Overall, the pegmatite exhibits a lower degree of evolution than the Ketchican Road beryl-type pegmatite, situated 0.4 km to the south, although it is interesting to note that the tantalum content of muscovite (122 ppm Ta) and its Nb/Ta ratio of 3.0 are similar to the Ketchican Road pegmatite (*see* Figure 20).

The oxide minerals in the pegmatite dike consist of ferrocolumbite (*see* Figure 22: Ta_2O_5 = 9 to 16 weight %) and gahnite ($ZnAl_2O_4$). The ferrocolumbite has tiny blebs of native bismuth. The garnet is intermediate almandine-spessartine.

In the outcrop along the western side of the road (UTM 411173E 5588515N, Zone 16), 2 samples of mafic metavolcanic rocks were collected about 20 m from the pegmatite dike:

- mafic metavolcanic rocks, biotite-rich (80 volume %) highly metasomatized and adjacent to a 30 cm thick quartz vein (02-FWB-40-04)
- mafic metavolcanic rock, with biotite porphyroblasts (5 volume %), collected about 3 m from 02-FWB-04 (02-FWB-40-05)

The bulk composition of 02-FWB-40-04 indicates highly anomalous levels of Rb (1485 ppm), Li (551 ppm), Cs (411 ppm), Sn (81 ppm), Ta (76 ppm) and Nb (30 ppm). Mafic metavolcanic rocks do not commonly contain such high levels of these elements (Taylor and McLennan 1985, p.181). The level of tantalum in 02-FWB-40-04 is the second highest bulk chemical concentration documented by this study. Such an anomalous level has never been previously observed by the authors within host rocks that have been metasomatized by rare-element pegmatite systems in Ontario. Lower, but still anomalous, levels of Li (179 ppm), Rb (176 ppm) and Cs (44 ppm) were found in 02-FWB-40-05.

The rare-element enrichment in the mafic metavolcanic rocks infers that an unexposed rare-element pegmatite system is located in the vicinity of these metasomatized mafic metavolcanic rocks. Therefore, more work is recommended in the area.

Peraluminous Granite and Pegmatitic Granite, English River Subprovince

Within the boundary zone between the English River and Wabigoon subprovinces (*see* Figure 2), north of Ottertail Creek on the North Jackfish Road, sporadic outcrops of white, peraluminous S-type granite and related pegmatitic granites were encountered. Such granites are commonly progenitors of rare-element pegmatites and indicated by the authors' work elsewhere in the Superior Province (Breaks, Selway and Tindle 2003a).

White, medium-grained biotite granite with elliptical-shaped, quartz-sillimanite nodules of was encountered at 02-JBS-46 (UTM 415779E 5593791N, Zone 16) (*see* Figure 3, back pocket). The biotite granite is cut by a quartz vein with a muscovite halo. The granite contains minor medium-grained pink garnet, which is magnesium-rich almandine. The high magnesium content in the garnet indicates crystallization in a relatively poorly evolved pegmatite-forming melt. One bulk composition of muscovite from the quartz vein (*see* Table 7) revealed low levels of rare-elements and high K/Rb and Nb/Ta ratios relative to pegmatites such as at North and South Aubry.

Molybdenite Occurrence on Jackfish Road

Mafic metavolcanic rocks at 02-JBS-33 (UTM 399372E 5587560N, Zone 16) (*see* Figure 3, back pocket) are crosscut by molybdenite-bearing quartz veins, biotite-rich veins and a sulphide-bearing quartz porphyry dike. This mineralized occurrence was discovered by M. and S. Stares in 2002 and was optioned by Linear Gold Corporation who undertook surface investigation in 2002.

The porphyry dike contains pyrite, pyrrhotite and molybdenite. Ferrimolybdite (a yellow alteration of molybdenite) occurs in outcrop. The mafic metavolcanic rocks also contain biotite alteration (phlogopite-siderophyllite) that contains slightly anomalous levels of some of the rare-elements (127 ppm Li and 32 ppm Cs: *see* Tindle, Selway and Breaks 2006 (MRD 210), Table 4). A thin section of an unaltered mafic metavolcanic rock revealed mostly hornblende and sulphides (pyrite and chalcopyrite) and minor quartz and sericitized feldspar. Bulk analyses of the biotite-rich mafic metavolcanic rocks, within 5 cm of contact with a molybdenite-rich quartz vein, contains elevated Cu (7729 ppm), Mo (1390 ppm) and S (0.88 weight %).

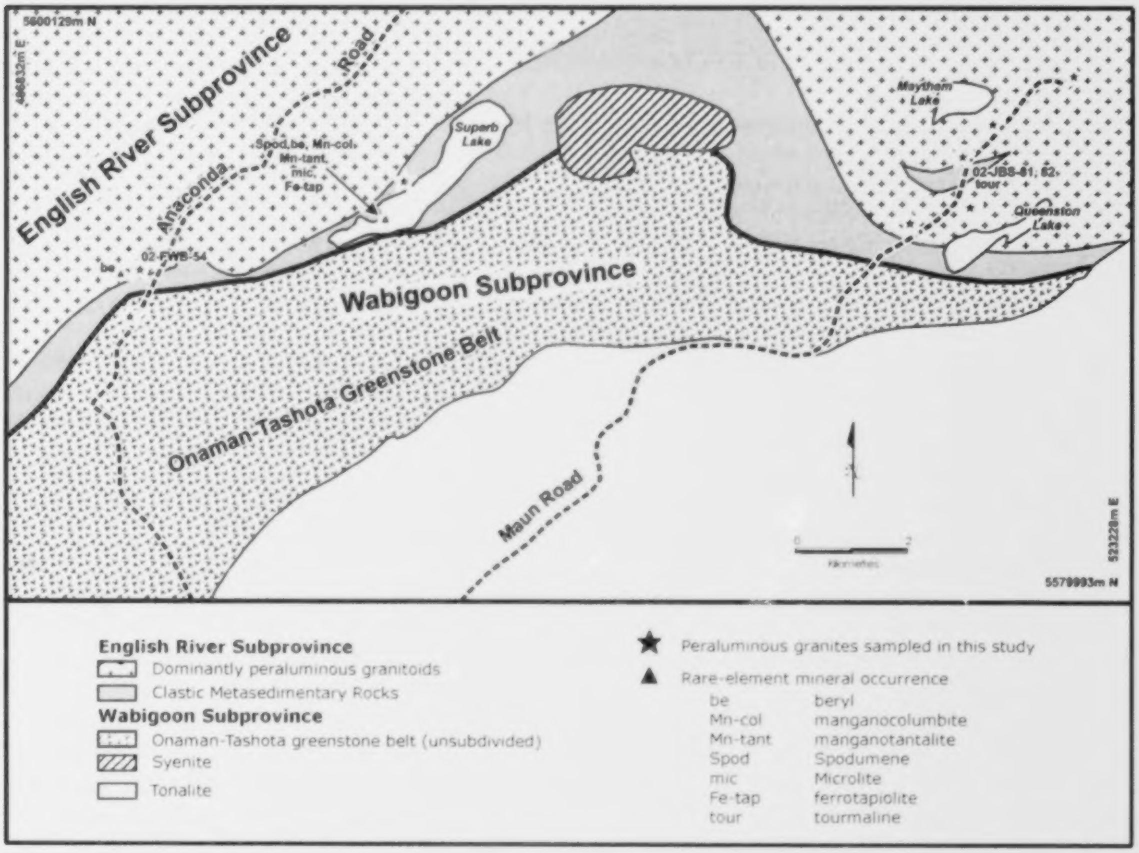
Wabigoon–English River Subprovincial Boundary Zone (Nakina area)

This area was briefly examined owing to the presence of the Superb Lake pegmatite, which had not been subjected to previous detailed mineralogical and chemical investigation (Figure 23). The most recent geological–structural investigation in the O'Sullivan Lake area (Figure 24, back pocket) was undertaken by Stott and Parker (1997). A reconnaissance examination was also directed at peraluminous granitic rocks and described by Stott and Parker (1997) and Parker and Stott (1998) in the Maytham–Queenston and Odman lakes areas (*see* Figure 23).

Two types of granites occur in the Nakina area: barren granite and fertile peraluminous pegmatitic granite. The fertile granites occur along the Wabigoon–English River subprovincial boundary and are hosted by clastic metasedimentary rocks (metawacke). The barren granites are hosted in migmatites and tonalite to the north of the fertile granites and further away from the subprovincial boundary zone, along the Terrier and Hauenstein roads. The barren granites are hosted by migmatites and tonalite. Locations of all samples selected for bulk rock and mineral analysis and electron microprobe investigation are presented in Figure 24 (back pocket).

BARREN GRANITIC ROCKS

The barren granites and related pegmatitic granites are pink or white and typically contain biotite as the sole mica mineral. However, muscovite-biotite granite and pegmatitic granite have also been found. The pink, biotite granite tends to be coarse grained, whereas the white, biotite granite tends to be fine grained. Magnetite is rare in the barren granites and garnet and tourmaline are absent. Rare fluorapatite was documented at 02-JBS-79 (UTM 495952E 5596689N, Zone 16) on the Anaconda Road in a coarse-grained biotite granite. Magnetite-biotite granite, on the Hauenstein Road (02-FWB-51: UTM 505746E 5601465N, Zone 16), reveals biotite blades up to 10 cm in length.


5600129m N
486832m E
English River Subprovince
Anaconda
Road
Spod,be, Mn-col, Mn-tant, mic, Fe-tap
Superb Lake
02-FWB-54
be
Maythem Lake
02-JBS-61, 62, tour
Queenston Lake
Wabigoon Subprovince
Onaman-Tashota Greenstone Belt
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0
2
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5579993m N
English River Subprovince
Dominantly peraluminous granitoids
Clastic Metasedimentary Rocks
Wabigoon Subprovince
Onaman-Tashota greenstone belt (unsubdivided)
Syenite
Tonalite
Peraluminous granites sampled in this study
Rare-element mineral occurrence
be beryl
Mn-col manganocolumbite
Mn-tant manganotantalite
Spod Spodumene
mic Microlite
Fe-tap ferrotapiolite
tour tourmaline

Figure 23. General geology and location of rare-element pegmatite mineralization in the English River–Wabigoon subprovincial boundary zone north of Nakina (geology *modified after* Stott and Parker 1997).

PERALUMINOUS PEGMATITIC GRANITES AND RARE-ELEMENT PEGMATITES

Fertile peraluminous, granitic rocks were noted at the following localities (*see* Figure 24, back pocket):

- Maun Lake Road near Maytham and Queenston lakes
- Abamasagi Lake Road in vicinity of its junction with the Anaconda Road
- northwestern shoreline of Superb Lake

Maytham–Queenston Lakes Pegmatitic Granite

Stott and Parker (1997, p.50) delineated a large mass of pegmatitic granite between these 2 lakes characterized by "abundant coarse muscovite, pink to lilac garnets and small enclaves of metasedimentary rock" (*see* Figure 23). The Maytham–Queenston lakes pegmatitic granite comprises an elliptical, 10 by 13 km body of peraluminous, massive, undeformed granite that lies in contact with metasedimentary rocks of the English River Subprovince (G.M. Stott, OGS, personal communication, 2002). Several outcrops scattered within a 10 km long transect, oriented roughly normal to the contact with metasedimentary rocks of English River Subprovince, were examined by the authors.

White potassic pegmatite and aplite are well exposed in a large outcrop on the Maun Lake Road between Maytham and Queenston lakes at 02-JBS-81 and 02-JBS-82 (UTM 518782E 5595264N, Zone 16). The potassic pegmatite displays several characteristics of a peraluminous, fertile granite, including radiating fans of green plumose muscovite-quartz intergrowths; graphic blocky potassium feldspar-quartz; local graphic tourmaline-quartz and garnet-green muscovite aplite layers. The potassic pegmatite also contains more muscovite than biotite, minor red garnet and blue apatite and is the most evolved outcrop in the Maytham–Queenston lakes area.

The Nb-Ta-oxide minerals, garnet and tourmaline occur in muscovite potassic pegmatite at these localities and are iron rich. Ferrocolumbite, ferrotantalite and ferrotapiolite occur sparsely as tiny inclusions in fluorapatite. An oxide mineral inclusion in a dark green fluorapatite consists of a ferrocolumbite core and a thin ferrotantalite rim. For all 3 oxide minerals (Figure 25b), the Mn/(Mn+Fe) has a narrow range from 0.05 to 0.15 with the following average Ta_2O_5 contents: ferrocolumbite (24.39 weight %), ferrotantalite (53.96 weight %) and ferrotapiolite (75.20 weight %).

The garnet and tourmaline contain minor amounts of magnesium that indicates poorly evolved compositions relative to lithium-rich pegmatites. Fine- to medium-grained red garnet in the aplite and garnet-muscovite potassic pegmatite consists of almandine with 14 to 35% spessartine. Some of the garnet grains are black due to partial locality alteration to biotite as at 02-FWB-56 (UTM 519552E 5595927N, Zone 16). The black tourmaline in the garnet-muscovite potassic pegmatite is schorl-dravite, magnesium-rich schorl and minor magnesium-rich schorl-foitite. The blue and dark green fluorapatite in the biotite-muscovite potassic pegmatite and muscovite potassic pegmatite is relatively MnO poor with (0.66 to 3.28 weight %).

One bulk composition of green muscovite from the muscovite potassic pegmatite contains low levels of Cs (13 ppm) and Rb (501 ppm) and a high Nb/Ta (12.9) relative to muscovite from rare-element pegmatites such as the North and South Aubry pegmatites (*see* Table 7: 02-FWB-56-01).

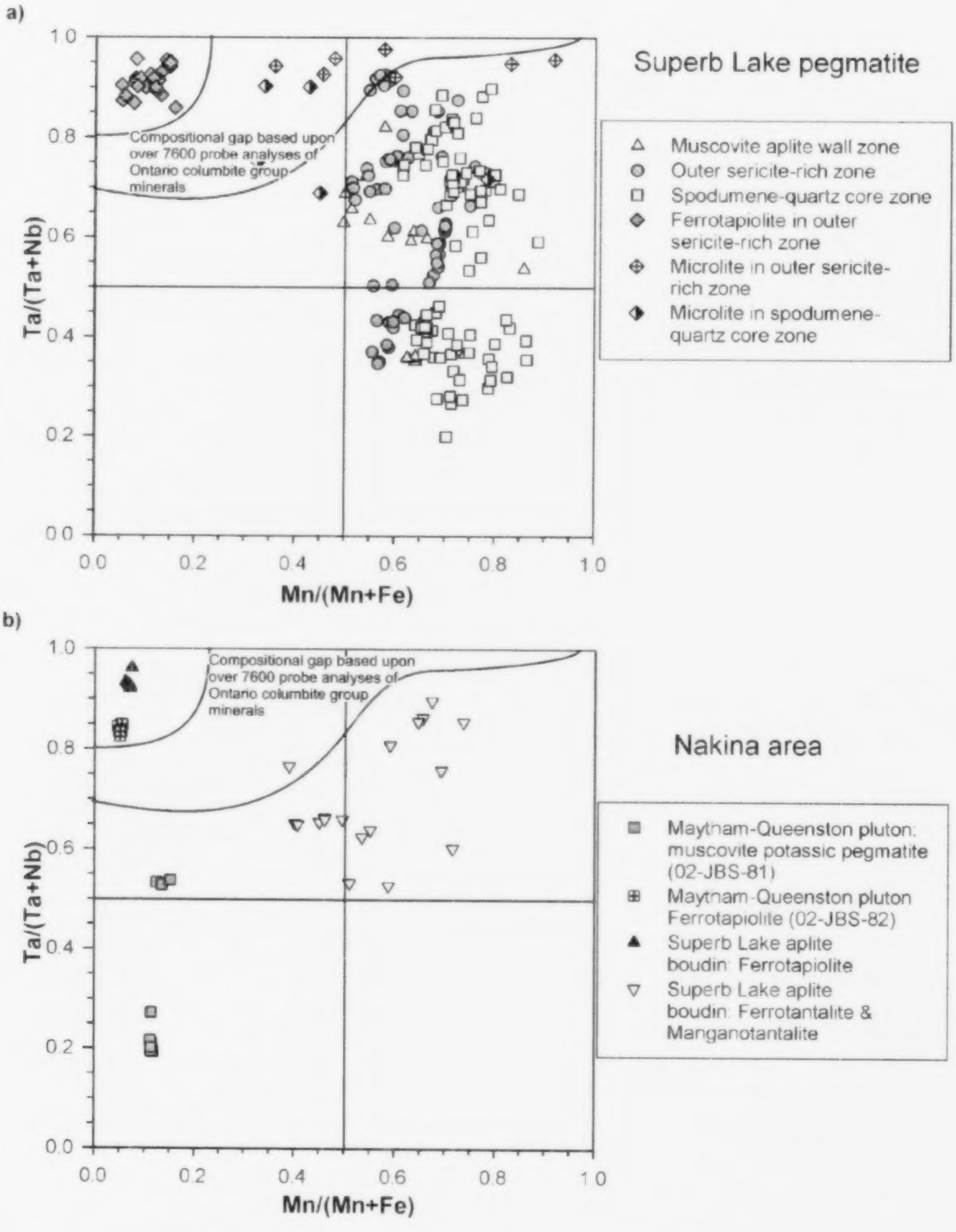

Figure 25. Columbite-tantalite quadrilateral plot (atomic ratios) for Nakina area rare-element pegmatites and pegmatitic granites. a) Superb Lake rare-element pegmatite, and b) Maytham–Queenston lakes pegmatitic granite and felsic boudin near Superb Lake pegmatite. Compositional gap between ferrotapiolite and ferrotantalite is based upon 7600 compositions of columbite-tantalite from Ontario. Microlite compositions may plot within this compositional space.

Garnet-muscovite potassic pegmatite layered with minor garnet-muscovite granite occurs at 02-FWB-56 (UTM 519552E 5595927N, Zone 16), also on the Maun Lake Road. Orientation of layering is 060/50S. Silver muscovite books, up to 2 by 20 cm, are abundant, whereas black tourmaline is sparse. Blocky potassium feldspar, up to 20 by 40 cm, is scattered throughout the main potassic pegmatite unit. Quartz-muscovite intergrowths, as radiating and blob-like entities up to 15 by 100 cm, represent a conspicuous feature (Photo 28) and is similar to other fertile granites examined by the authors, such as near Onion Lake and at the South Aubry spodumene pegmatite (Breaks, Selway and Tindle 2001). The garnet and tourmaline in the garnet-muscovite potassic pegmatite is iron rich and contains minor amounts of magnesium. The red-brown fine- to medium-grained garnet is almandine with 20 to 24% spessartine. The black graphic intergrowth of quartz-tourmaline is composed of schorl-dravite.

Further to the east at 02-FWB-57 (UTM 524118E 5597656N, Zone 16), the mineral assemblage within the pegmatitic granite changes, marked by a decrease in the abundance of muscovite and disappearance of tourmaline, into a muscovite-garnet-biotite potassic pegmatite containing narrow layers of garnet-biotite aplite.

Three potassium feldspar bulk compositions (*see* Tindle, Selway and Breaks 2006 (MRD 210), Table 5), taken across a 5 km section of the Maytham–Queenston lakes pegmatitic granite mass, reveal a progressive westward increase in evolution in the sequence: 02-FWB-57 → 02-FWB-56-02 → 02-JBS-81. The cesium and rubidium levels in the potassium feldspar, respectively, increase from 5.1 to 11 to 44 ppm Cs and 442 to 523 to 674 ppm Rb.

Red garnet occurs in 2 outcrops of white, two-mica peraluminous granite at 02-JBS-80 (UTM 512617E 5588583N, Zone 16) and 02-JBS-83 (UTM 520772E 5597745N, Zone 16). The dark pink, fine- to medium-grained garnet is magnesium-bearing almandine with 14 to 25% spessartine. The garnet crystals are zoned with iron- and magnesium-rich cores and manganese-rich rims and have locally altered to biotite.

Photo 28. Garnet-muscovite potassic pegmatite unit from Queenston–Maytham lakes pluton with abundant plumose muscovite-quartz intergrowths.

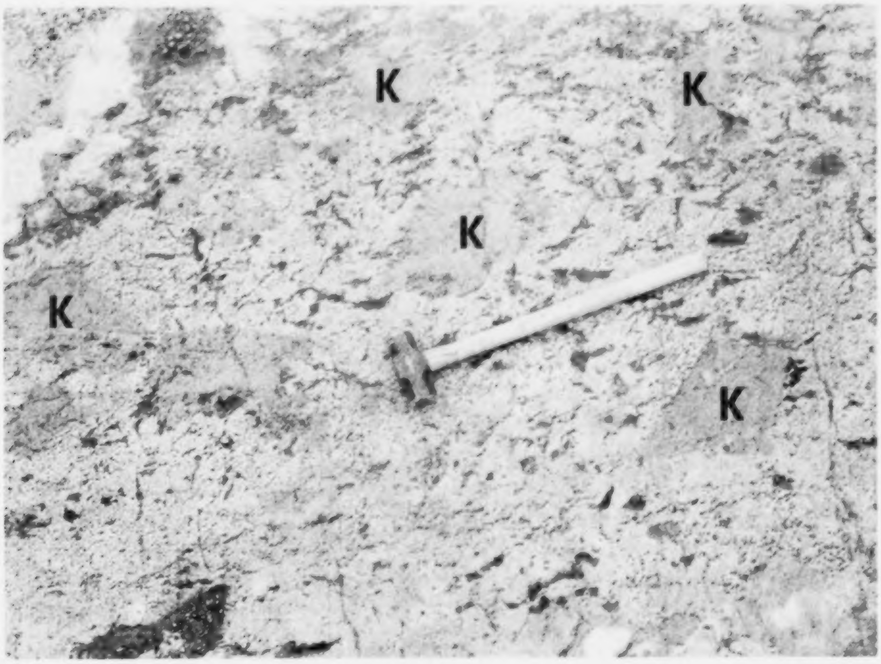

Photo 29. Pegmatitic leucogranite with pink graphic megacrysts of potassium feldspar+quartz (K) embedded in a white matrix of plagioclase, quartz and abundant plumose intergrowths of muscovite-quartz. Abamasagi Lake Road.

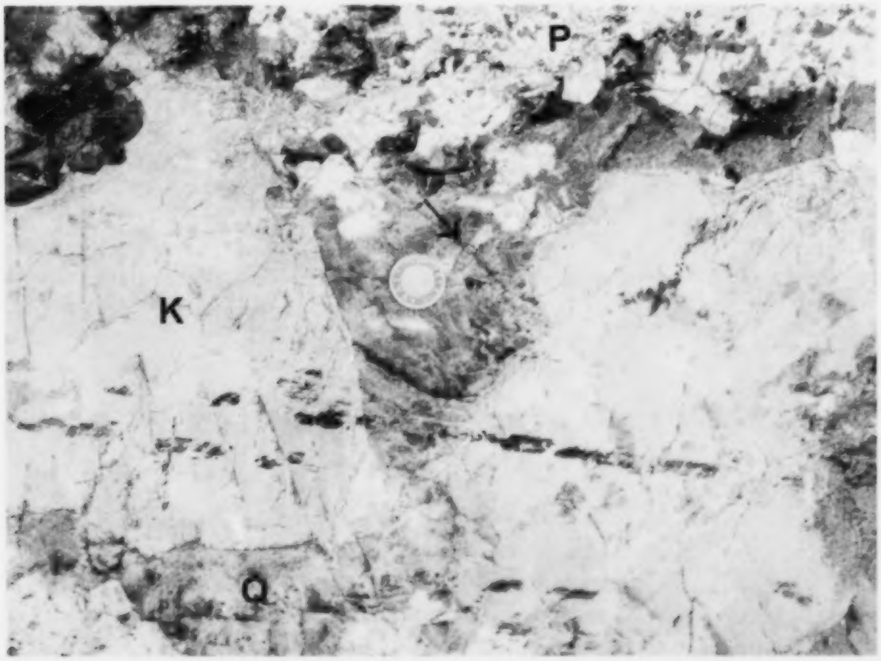

Photo 30. Pegmatitic leucogranite on the Abamasagi Lake Road that grades into segregation of blocky potassium feldspar (K) and quartz (Q). Small crystal of green beryl (arrow) occurs in the quartz.

Abamasagi Lake Road Pegmatitic Granite

A well-exposed, clean, glacially polished outcrop of garnet-biotite-muscovite pegmatitic leucogranite was observed at 02-FWB-54 (UTM 490691E 5591192N, Zone 16) along the Abamasagi Lake Road near the junction with the Anaconda Road (*see* Figure 24, back pocket). Fertile peraluminous granite units are well exposed on glacially polished surfaces at this locality:

- pegmatitic leucogranite
- sodic aplite layers
- quartz-rich patches with blocky potassium feldspar and sparse green beryl
- potassic pegmatite segregations

The main unit is a garnet-biotite-muscovite pegmatitic leucogranite with abundant plumose intergrowths of quartz-muscovite, which is quite reminiscent of some internal units in the South Aubry pegmatite. This pegmatitic leucogranite unit is conspicuous due to numerous, bright pink megacrysts of graphic quartz-potassium feldspar intergrowths that are up to 20 by 32 cm in size (Photo 29). These megacrysts are embedded within a white matrix that is mainly a graphic intergrowth of quartz and albite. Plumose intergrowths of coarse-grained muscovite and quartz are interstitial to the albite crystals.

The pegmatitic leucogranite locally is gradational into very coarse patches that are quartz rich with blocky potassium feldspar crystals up to 40 cm in diameter. Irregular masses of potassic pegmatite also occur along the periphery of the quartz patches and comprise an irregular aggregate of blocky potassium feldspars. One of the quartz-rich patches contains sparse, faint green, beryl crystals up to 0.8 cm in diameter and 3 cm parallel to the length of the crystal (Photo 30). Garnets are found locally in the quartz-rich patches and reach up to 1.5 by 2 cm in size. The red garnet in the quartz-rich patch is almandine with 24 to 33% spessartine. The pale green beryl is Cs_2O poor with 0.08 weight %.

Sparse green, sugary aplite are interlayered with an albite-rich, coarser grained, 5 to 10 cm thick unit garnet-biotite-quartz-albite that locally contain bright pink, blocky, potassium feldspar crystals (*see* Photo 29). The garnet in the garnet-muscovite aplite is almandine with 27 to 31% spessartine.

Bulk composition of green muscovite (*see* Table 7: 02-FWB-54-02) reveals levels of elements indicative of a fertile pegmatitic granite system and, particularly the elevated Ta (63 ppm), infers the presence of beryl-type pegmatites (*see* Figure 20).

A small, white, pegmatite dike, mostly covered in a 1 by 3 m outcrop on the west side of the Anaconda Road (02-FWB-55: UTM 491395E 5590709N, Zone 16; *see* Figure 24), consists of massive garnet-muscovite potassic pegmatite. The potassic pegmatite, hosted by unmigmatized metawacke, contains coarsely graphic, white potassium feldspar, green muscovite and garnet up to 0.5 cm in diameter. The orange-brown to orange-pink garnet is almandine with 29% spessartine. The garnet has a manganese-rich core and an iron-rich rim.

Blocky potassium feldspar from the dike centre (*see* Tindle, Selway and Breaks 2006 (MRD 210), Table 5) contains elevated Rb (2418 ppm) and Cs (147 ppm) and low K/Rb (44) and K/Cs (727) ratios that represent the most evolved compositions found in the Abamasagi Lake Road area and compare with fertile granite-pegmatite systems elsewhere as at Separation Rapids pegmatite field (Breaks and Tindle 2002).

A large outcrop of pink to locally white, biotite-muscovite potassic pegmatite and pink, medium-grained equigranular biotite granite is exposed near the Anaconda Road at 02-FWB-52 (UTM 491639E 5591905N, Zone 16). The pink, perthitic, blocky potassium feldspar, up to 15 by 30 cm, is less evolved than 02-FWB-55 and 02-FWB-53 (*see* Tindle, Selway and Breaks 2006 (MRD 210), Table 5) as indicated by the lower Rb (759 ppm) and Cs (18 ppm) and consequently higher K/Rb (133) and K/Cs (5612).

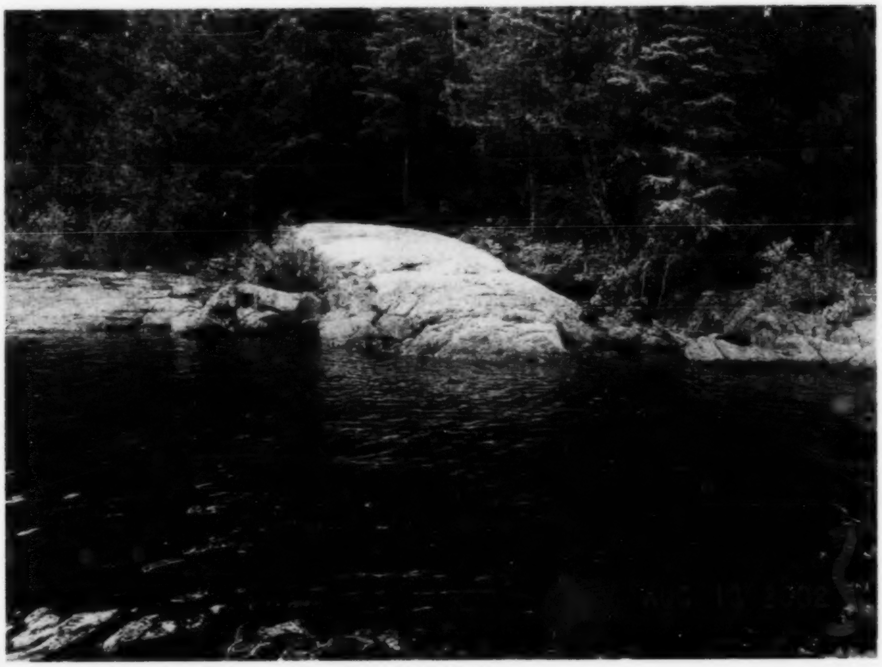

Photo 31. View of the Superb Lake pegmatite looking west.

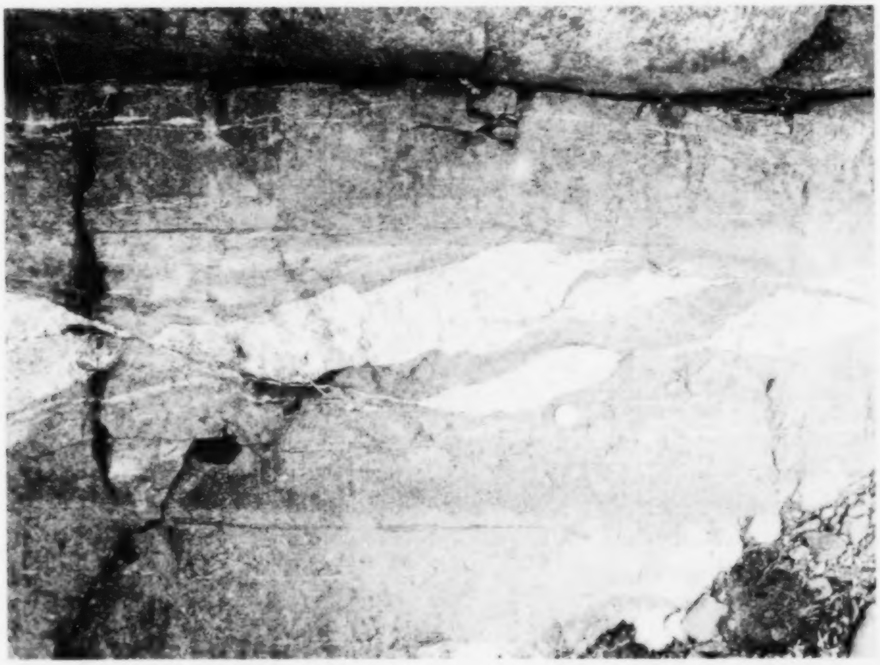

Photo 32. Rotated aplite boudins in a deformed dike related to Superb Lake pegmatite.

Northwest Shoreline of Superb Lake

An exposure of sheared pegmatitic granite, which represents a dike at least 30 m in width, is exposed along the northwest shoreline of Superb Lake, northwest of the Superb Lake pegmatite at 02-JBS-66 (UTM 499608E 5593833N, Zone 16: *see* Figure 24, back pocket). The main unit comprises garnet-muscovite potassic pegmatite accompanied by garnet-muscovite aplite. Most of the shearing is focussed in the aplite unit. This dike, previously mapped by Parker and Stott (1998), is hosted by metasedimentary rocks of the English River Subprovince.

The fine- to medium-grained dark pink to red garnet in the garnet-muscovite potassic pegmatite is almandine with 21 to 36% spessartine. The garnet in the garnet-muscovite aplite is fine- to medium-grained (up to 2.5 mm in diameter) dark pink almandine with 17 to 22% spessartine. Garnets from both rock types are weakly altered to biotite.

Superb Lake Pegmatite

The Superb Lake pegmatite (02-JBS-63: UTM 499104E 5592820N, Zone 16: *see* Figures 23 and 24) occurs within medium-grade, metasedimentary rocks of the English River Subprovince directly adjacent to its boundary with the Onaman–Tashota greenstone belt in the O'Sullivan Lake area (Photo 31). The lithium-rich pegmatite was apparently discovered around 1955 by unspecified individuals (Mulligan 1965, p.63) and evidence of work possibly from that date was noted in an old blast pit. A large bulk sample collected from the pegmatite by G.M. Stott from the blast pit area (G.M. Stott, OGS, unpublished data, 1998) contained Ta above the detection limit of 350 ppm, 142 ppm Be, 80 ppm Nb, 1464 ppm Rb, 99 ppm Cs and 56 ppm Sn. In addition, 4 rock specimens with columbite-group minerals were provided by G.M. Stott (OGS; samples 97-GRS-215A to -215D). The work undertaken in this project included a thorough Wajax power washing of the pegmatite surface prior to mineralogical and bulk rock sampling.

The pegmatite has a minimum exposed strike length of 16 m and its width varies from 2.5 m at the shoreline to a maximum of 3.7 m where an old blast pit was excavated. Most of the blasted material appears to have been removed or was blasted into the lake. The contact between the pegmatite and well foliated, biotite, metawacke and metapelite host rocks is only exposed along the south between the lake and the blast pit. The metasedimentary host rock has been metasomatized, as it contains abundant siderophyllite-zinnwaldite and muscovite and accessory apatite along the southern contact with the pegmatite.

The pegmatite exhibits deformation by internal thin shears that are locally anastomosing and by several re-entrants of metasedimentary host rock into the pegmatite along the southern contact. The contact is not planar as would be the case in a posttectonic emplaced pegmatite such as the Tot Lake pegmatite in the Dryden area (Breaks and Janes 1991).

Several narrow, aplite-like veins are situated within 30 m of the main pegmatite and reveal important evidence for the style of deformation. These pegmatites are variably deformed and one dike, situated 12 m south of the Superb pegmatite has been completely dismembered into a train of Z-shaped, rotated boudins (Photo 32). These dikes are related to the Superb Lake pegmatite as indicated by white beryl and numerous specks of black Ta-Nb oxide minerals.

The orientation of the pegmatite contact is variable due to deformation as in evidence from the varied measurements: 260/58N, 247/50N, 030/32N and 090/82N. The contact appears particularly warped adjacent to a local zone of intense phosphate-mica alteration of the metasedimentary host rock. Metasomatism of the host rocks is generally insignificant except for a 50 by 110 cm area of intense mica-rich alteration along the southern contact that consists of biotite porphyroblasts, fine-grained yellow-green sericite and local concentrations of blue-green apatite.

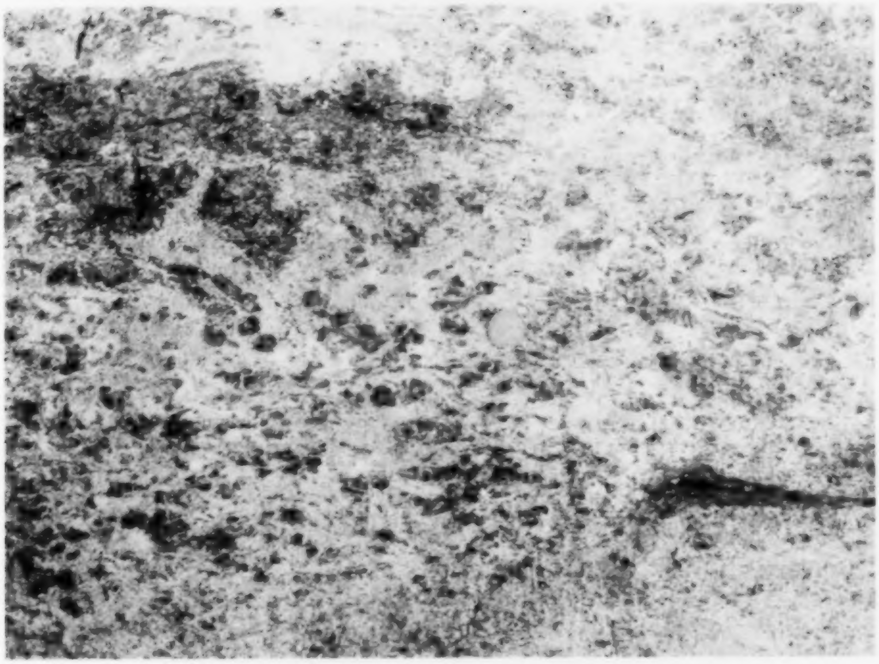

Photo 33. Sericite-rich zone from the Superb Lake pegmatite.

Photo 34. Coarse, partially altered spodumene from the spodumene-quartz core zone.

INTERNAL ZONES

Vague internal zonation occurs in the pegmatite that consists of the following units:

- wall zone of muscovite-quartz-albite aplite
- sericite-rich outer zone
- intermediate zone of muscovite-quartz-spodumene-albite
- central core of muscovite-potassium feldspar-spodumene-quartz

The aplite wall zone of the pegmatite consists of a 50 cm wide assemblage of muscovite-quartz-albite. Transverse quartz veins, 10 to 35 cm in width and up to 1.9 m in length, are oriented normal to the dike contact. These veins are devoid of other pegmatite minerals.

The sericite-rich outer zone is discontinuously evident along the southern margin of the pegmatite as a finer-grained assemblage of quartz-spodumene-sericite-albite. This unit is characterized by masses of rich in yellow-green sericite that comprise about 30 volume % of the rock (Photo 33). It is plausible that the yellow-green masses represent completely altered spodumene; however, no relic cores of unaltered spodumene were identified in contrast to "tiger eye" textures observed in the Tot Lake pegmatite (Breaks 1989) and at the Swole Lake pegmatite. Alternatively, the sericite masses may represent concentrations of potassium that were released during albitization of potassium feldspar. The potassium may have been redistributed during shearing deformation which obviously affects this part of the pegmatite. Purple fluorite and liberite (Li_2BeSiO_4) are sporadically distributed in the unit.

An intermediate zone of fine-grained muscovite-quartz-spodumene-albite occurs indistinctly adjacent to the wall zone and grades into the coarser spodumene-quartz core.

The central, coarser grained muscovite-potassium feldspar-spodumene-quartz core unit (Photo 34) is 50 to 70 cm wide and 6 m in strike length. This zone contains the coarsest spodumene crystals that may be up to 4 by 35 cm in sections parallel to the long axis. These grey to pale green spodumene crystals are typically randomly oriented. A significant number of spodumene crystals are partially to completely altered to aphanitic, yellow green and dark green black secondary minerals. One large crystal that resembled blocky potassium feldspar on the surface of the outcrop was revealed to be completely albitized potassium feldspar when a channel sample was cut. Lithiophilite was identified as an accessory mineral in the spodumene core zone.

MINERAL CHEMISTRY OF SUPERB LAKE PEGMATITE

The metasomatized metasedimentary host rock contains abundant "biotite" which has a composition of siderophyllite-zinnwaldite with Rb_2O = 0.87 to 0.91 weight %, Cs_2O = 0.26 to 0.29 weight % and calculated Li_2O = 1.72 to 1.89 weight % (lithium cannot be measured by electron microprobe techniques and has been calculated on stoichiometric criteria, *see* Tindle and Webb 1990), and muscovite with Rb_2O = 0.01 to 0.60 weight %, Cs_2O = 0.04 to 0.12 weight % and calculated Li_2O = 0.20 to 0.40 weight %. The fluorapatite is relatively MnO-poor (0.81 to 1.78 weight %). Rubidium-, cesium- and lithium-enriched micas and fluorapatite in the metasedimentary host rocks suggest that pegmatitic fluids interacted with the host rock to alter its composition.

The muscovite aplite wall zone contains abundant platy albite, quartz and muscovite and minor sericitized feldspar in thin section. Accessory minerals include Ta-Nb-oxide minerals, fluorapatite, potassium feldspar and liberite. The Ta-Nb-oxide minerals (Figure 25a) are manganocolumbite (38.59 to

40.20 weight % Ta_2O_5), manganotantalite (53.88 to 73.79 weight % Ta_2O_5) and rare ferrotantalite (61.71 weight % Ta_2O_5) with an overall average Mn/(Mn+Fe) = 0.62. Manganotantalite with strong oscillatory zonation was observed in 97-GRS-215D. The fluorapatite contains MnO = 0.26 to 3.49 weight %. The potassium feldspar contains 0.05 to 0.22 weight % Rb_2O and up to 0.02 weight % Cs_2O.

In the sericite-rich zone, the Ta-Nb oxide minerals and fluorapatite have moderate amounts of manganese, but the garnet is relatively manganese rich. The sericite outer zone contains accessory manganocolumbite (38.29 to 46.74 weight % Ta_2O_5), manganotantalite (51.38 to 76.32 weight % Ta_2O_5), ferrotapiolite (74.63 to 83.68 weight % Ta_2O_5) and rare microlite (74.14 to 79.59 weight % Ta_2O_5). The columbite-tantalite exhibits oscillatory zoning with manganocolumbite cores and manganotantalite rims. The manganocolumbite and manganotantalite has an average Mn/(Mn+Fe) of 0.62 that is similar to the aplite zone. The green fluorapatite contains 0.75 to 3.37 weight % MnO. Pink anhedral garnet is dominantly spessartine (64 to 79%) with subordinate almandine (19 to 36%).

Ferrotapiolite is the main Ta-Nb-oxide mineral in one sample from the sericite-rich zone at 97-GRS-215A. This mineral forms anhedral patchy grains with irregular margins that have been partially resorbed and replaced with microlite. Some microlite is euhedral that indicates crystallization of the pegmatite began in the ferrotapiolite stability field, but ended in the microlite field. Both minerals contain exceptionally high Ta_2O_5 contents: ferrotapiolite (average of 79.3 weight % Ta_2O_5) and microlite (average of 77.2 weight % Ta_2O_5). Ferrotapiolite elsewhere in the Superb Lake pegmatite system has only been found in the aplite boudins.

Potassium feldspar, muscovite and beryl in the outer sericite-rich zone contain moderate amounts of rubidium and cesium. The white primary potassium feldspar is strongly albitized, and the beige to pale orange, anhedral secondary potassium feldspar (0.14 to 0.21 weight % Rb_2O and up to 0.02 weight % Cs_2O) mantles purple fluorite. Laumontite ($CaAl_2Si_4O_{12}\cdot 4H_2O$) occurs as a beige, 0.5 by 3 by 5 cm, aggregate of) intergrown with potassium feldspar as identified by X-ray diffraction.

Yellow-green muscovite contains Rb_2O (0.38 to 0.87 weight %) and Cs_2O up to 0.12 weight %. A white beryl crystal (3.5 by 2.5 cm across) 1 m from the south contact contains Na_2O = 0.82 to 1.34 weight % and Cs_2O = 0.11 to 0.27 weight %. Liberite (Li_2BeSiO_4) is an accessory lithium-and beryllium-bearing mineral in this pegmatite zone.

The spodumene-quartz core zone is more evolved than the aplite and sericite-rich zones, as indicated by the more manganese-rich oxide minerals and fluorapatite and the presence of lithiophilite. The spodumene-quartz core zone contains accessory manganocolumbite (23.23 to 47.25 weight % Ta_2O_5), manganotantalite (54.19 to 78.21 weight % Ta_2O_5) and rare microlite (58.57 to 68.30 weight % Ta_2O_5). The manganocolumbite and manganotantalite has an average Mn/(Mn+Fe) of 0.73 higher than that of the aplite and sericite zones. The columbite-tantalite is characterized by minor to strong oscillatory zonation and forms prismatic laths in which the overall change in composition is from tantalum-poor to tantalum-rich compositions. The green fluorapatite is relatively MnO rich (0.03 to 5.89 weight %). Lithiophilite ($LiMnPO_4$) is an accessory lithium-bearing mineral with an average Mn/(Mn+Fe) = 0.93.

Potassium feldspar, muscovite and beryl in the spodumene-quartz core zone are relatively rubidium and cesium enriched, which indicate that the spodumene core zone is more evolved than the aplite and sericite zones. The grey, primary potassium feldspar contains Rb_2O (1.16 to 1.30 weight %) and Cs_2O (0.06 to 0.10 weight %). The yellow-green muscovite contains higher Rb_2O (0.71 to 1.83 weight %) and Cs_2O (0.04 to 0.28 weight %). White beryl contains Cs_2O = 0.18 to 0.78 weight % and Na_2O = 1.18 to 2.07 weight %.

Aplite boudins, hosted by metasedimentary rocks 10 m south of the Superb Lake pegmatite (02-JBS-64 and 02-JBS-65), are remnants of a thin dike related to the Superb Lake pegmatite. A thin section of 02-JBS-64, from a 13 by 70 cm boudin, reveals abundant fine-grained, equant, orange-white albite, coarse-grained, grey microcline phenocrysts and quartz and accessory Ta-Nb oxide minerals, purple fluorite, garnet and rare chlorite. Fine- to medium-grained, black-brown grains surrounded by rusty halos are not oxide minerals, but actually comprise quartz with hematite and fluorite. The altered garnet is enriched in spessartine (55 to 67%) and lesser almandine (33 to 45%). The potassium feldspar contains 0.13 to 0.46 weight % Rb_2O and up to 0.04 weight % Cs_2O.

A second aplite boudin (02-JBS-65), 17 by 55 cm, was sampled 5 m adjacent to 02-JBS-64 and contains quartz, yellow-green muscovite, white albitized potassium feldspar, accessory Ta-Nb oxide minerals, garnet and beryl. The Ta-Nb-oxide minerals (*see* Figure 25b) comprise ferrotantalite (62.77 to 70.43 weight % Ta_2O_5), manganotantalite (54.04 to 79.02 weight % Ta_2O_5) and ferrotapiolite (80.63 to 83.13 weight % Ta_2O_5). The average Mn/(Mn+Fe) for ferrotantalite and manganotantalite is 0.55.

The Ta-Nb-oxide grains have columbite-tantalite cores and ferrotapiolite rims that indicate the pegmatite-forming melt increased in tantalum content during the crystallization of the felsic boudins. Quartz contains tiny inclusions of manganotantalite and manganese-poor fluorapatite with MnO = 0.15 weight %. The manganese is preferentially partitioned into the manganotantalite relative to fluorapatite. The muscovite cores are enriched in Rb_2O (0.91 to 1.19 weight %) and Cs_2O (0.91 to 1.19 weight %), whereas the muscovite rims do not contain detectable levels of these elements that suggests late-stage replacement may have caused a depletion.

EXPLORATION RECOMMENDATIONS

The brief work undertaken by this project in the O'Sullivan Lake area has revealed an interesting assortment of potentially fertile, peraluminous pegmatitic granites (Maytham–Queenston lakes, near Odman Lake and on Superb Lake), coupled with a known, lithium-rich, rare-element pegmatite occurrence. The Maytham–Queenston pluton, in particular, resembles fertile pegmatitic granites observed by the authors in the Allison Lake batholith and in the Onion Lake area (Breaks, Selway and Tindle 2001).

The new rare-element pegmatite discovery at 02-FWB-54, coupled with chemically evolved potassic pegmatite found at 02-FWB-55, indicate that pegmatitic granites in this area are at least locally fertile. Hence, the Superb–Odman–Abamasagi lakes area, in the vicinity of the Wabigoon–English River subprovinces boundary, should be prospected for further rare-element mineralization.

Quetico Subprovince (Hearst Area)

Rare-element pegmatites have widespread distribution in the metasedimentary-dominant Quetico Subprovince covering at least a 540 km strike length from west to east:

- spodumene-subtype pegmatites at Wisa Lake, Lac La Croix area
- fertile granites and beryl-type pegmatites in Niobe–Nym lakes and Onion Lake areas
- albite-spodumene-type pegmatites of the Georgia Lake area
- complex-type, lepidolite-subtype Lowther Township pegmatite near Hearst (Breaks, Selway and Tindle 2003a)

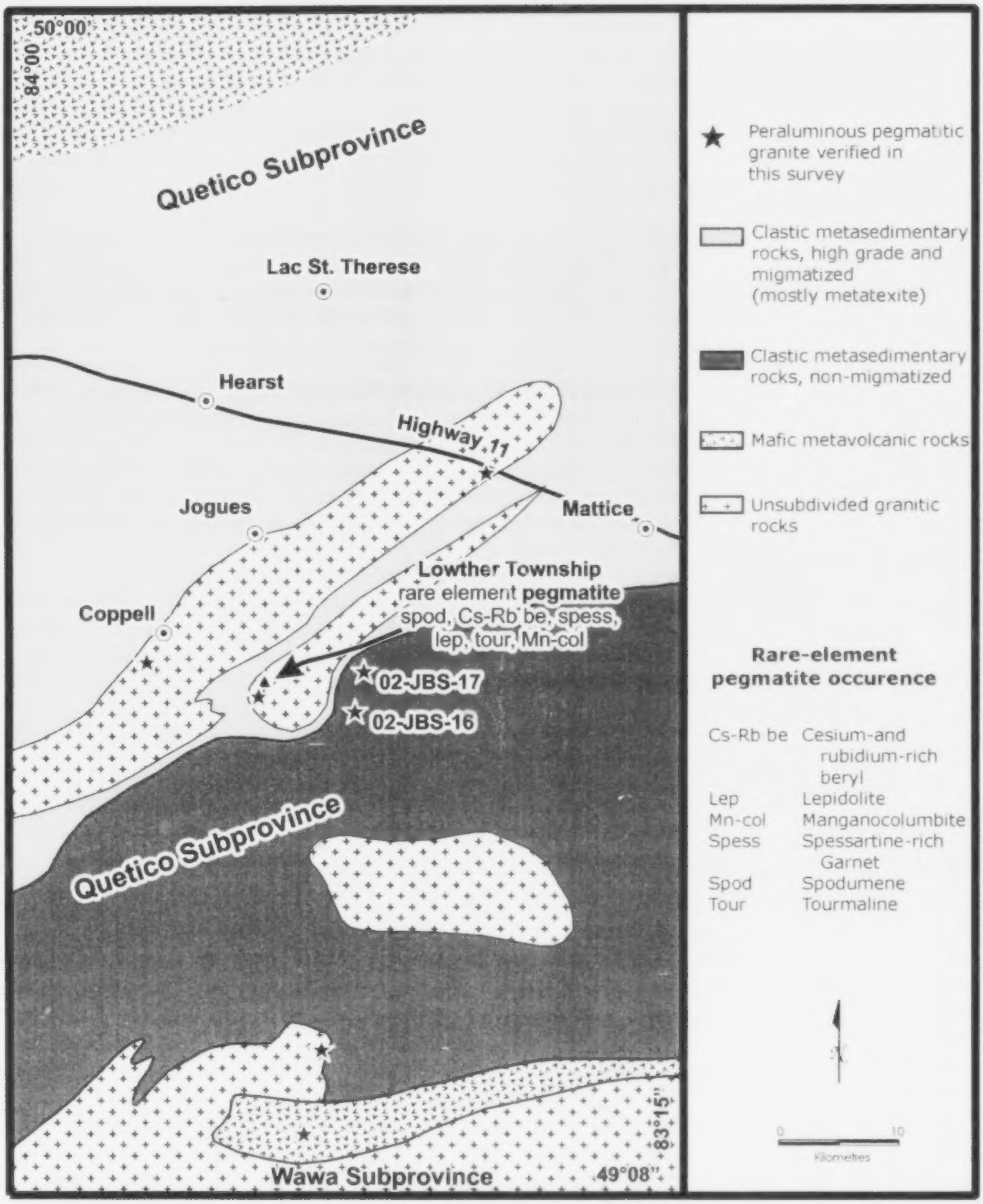
50°00'
84°00'
Quetico Subprovince
Lac St. Therese
Hearst
Highway 11
Jogues
Mattice
Coppell
Lowther Township
rare element pegmatite
spod, Cs-Rb be, spess,
lep, tour, Mn-col
02-JBS-17
02-JBS-16
Quetico Subprovince
Wawa Subprovince
83°15'
49°08"
★ Peraluminous pegmatitic granite verified in this survey
Clastic metasedimentary rocks, high grade and migmatized (mostly metatexite)
Clastic metasedimentary rocks, non-migmatized
Mafic metavolcanic rocks
Unsubdivided granitic rocks
Rare-element pegmatite occurence
Cs-Rb be Cesium-and rubidium-rich beryl
Lep Lepidolite
Mn-col Manganocolumbite
Spess Spessartine-rich Garnet
Spod Spodumene
Tour Tourmaline
N
0
10
Kilometres

Figure 27. General geology and location of rare-element pegmatite mineralization in the Hearst area.

Furthermore, the restriction of rare-element pegmatites to boundary zones with adjacent subprovinces is not completely applicable to the Quetico Subprovince. It is apparent that rare-element mineralization is distributed across the Quetico Subprovince and a large percentage of rare-element pegmatites are concentrated within the centre of the subprovince, as for example, at Georgia Lake (Pye 1965; Breaks, Selway and Tindle 2003b).

The pegmatites in the Quetico Subprovince are hosted by medium-grade unmigmatized metawacke with subordinate interbedded metapelite (e.g., spodumene-subtype Wisa Lake pegmatite and albite-spodumene-type Georgia Lake pegmatites) and by their parent granite (e.g., petalite-subtype MNW pegmatite and lepidolite-subtype Lowther Township pegmatite) (Pye 1965; Breaks, Selway and Tindle 2003a, 2003b).

Reconnaissance evaluation of potentially fertile, peraluminous pegmatitic granitic rocks was undertaken in a 1000 km^2 area in the vicinity of the Town of Hearst. This area was selected due to the presence of a highly evolved, rare-element pegmatite in Lowther Township (complex-type, lepidolite-subtype based on the pegmatite classification of Černý 1991). This pegmatite is unique because it is hosted by its fertile, pegmatitic granite, parent pluton (Breaks, Selway and Tindle 2001). This occurrence is situated within the central part of the Quetico Subprovince, similar to previously examined rare-element pegmatite localities (Breaks, Selway and Tindle 2001) at Wisa Lake and in the Georgia Lake area (Pye 1965). Work in the Hearst area was also deemed important because a geochemical and mineralogical database relevant for rare-element deposits does not exist in this region. The locations of bulk rock and electron microprobe compositions from the Hearst area can be found in Figure 26 (back pocket).

GENERAL GEOLOGY

Most of the Hearst area was examined during reconnaissance geological mapping in the late 1960s (Bennett et al. 1966a, 1966b, 1967a, 1967b) as part of Operation Kapuskasing (Berger 1986). Detailed mapping in the area has only been undertaken by Berger (1985) and Berger, MacMillan and Roy (1986), who focussed upon metavolcanic belts that form part of the Quetico–Wawa subprovincial boundary zone. Between longitude 84°00"and 85°55", there is no record of any geological mapping in the Quetico Subprovince south of the boundary with the Wabigoon Subprovince along Highway 11. The area west of longitude 85°55" along Highway 11 was mapped by Amukun (1983).

A generalized map of the Hearst area is presented in Figure 27. The area is marked by 2 northeast-trending, *en-échelon* masses of unsubdivided granitic rocks (Bennett et al. 1967a, 1967b) that approximately corresponds with the metamorphic transition from medium-grade, unmigmatized metawacke and interbedded metapelites (in Shetland, Staunton, Orkney, Ebbs, Scholfield, Caithness and Rykert townships) to high-grade, layered migmatites in a large area to the northwest, between the towns of Hearst, Jogues and Lac St. Therese. The main rock type is metatexite that was mapped previously as "biotite-quartz-feldspar gneiss" by Bennett et al. (1967a, 1967b). This rock type has variable, foliation-concordant, white granitic to pegmatitic leucosome (5 to 20%) that has been invaded by later, generally pink, dikes and small masses of biotite-bearing, potassic pegmatite and fine- to medium-grained biotite granite.

Barren Biotite Granite and Pegmatitic Granite

An extensive area underlain by weakly peraluminous, I-type, pink, fine- to medium-grained granite and pegmatitic granite and interleaved migmatitic metasedimentary rocks with derived S-type peraluminous granite was encountered in the Hearst–Bannerman Lake area. These granitic rocks are widespread over a minimum area of 30 by 45 km that apparently corresponds with a southwest-northeast-oriented area of higher total magnetic field (Gupta 1991: –40 to 180 nT), in contrast to the lower magnetic intensities evident over migmatitic metasedimentary rocks of the Quetico Subprovince (Gupta 1991: –220 to –300 nT). The more intense and "grainy" magnetic pattern is attributed to the widespread occurrence of magnetite in the pink granite pegmatitic granitic rocks. The magnetic pattern also suggests a termination of the zone of I-type granites just east of the Kabinakagami River.

The ultimate distribution of these granitic rocks to the northeast is unknown, but could extend at least to the Kapuskasing structure, based upon continuity of the same magnetic pattern. Magnetite is completely lacking in the more strongly peraluminous, S-type granites associated with migmatitic metasedimentary rocks of the Quetico Subprovince. Garnet commonly occurs in both I-type and S-type granitic rocks of the Hearst area. Outcrop observations reveal that the I-type granitic rocks are interleaved with layered migmatitic metasedimentary rocks.

Peraluminous granites derived from partial melting of metawacke and metapelites of the Quetico Subprovince are more strongly peraluminous than the barren pink granite and related pegmatitic granites situated north and northwest of Hearst, owing to the presence of primary muscovite, lack of magnetite (*see* "McCrea–Shetland Pegmatitic Granite Zone") and are prevailingly white on fresh surface.

Field relations, as revealed at 02-JBS-05 (UTM 298937E 5509915N, Zone 17) west of Hearst on Highway 11, on the border between Way and Hanlan townships, indicate that pink, fine- to medium-grained, biotite granite is crosscut by a 60 cm-thick dike of white, more strongly peraluminous potassic pegmatite of probable S-type origin (Photo 35). The dike is zoned with a fine-grained biotite muscovite granite outer zone that grades into a coarse-grained muscovite potassic pegmatite core zone. The coarse-grained green muscovite in the potassic pegmatite is up to 2 cm across by 2.5 cm thick. In thin section, the core zone contains quartz, muscovite, microcline altered to sericite, minor plagioclase altered to sericite, chlorite and rare pyrite. Rare tourmaline-quartz intergrowths occur in the muscovite potassic pegmatite and the tourmaline has a composition of schorl-dravite.

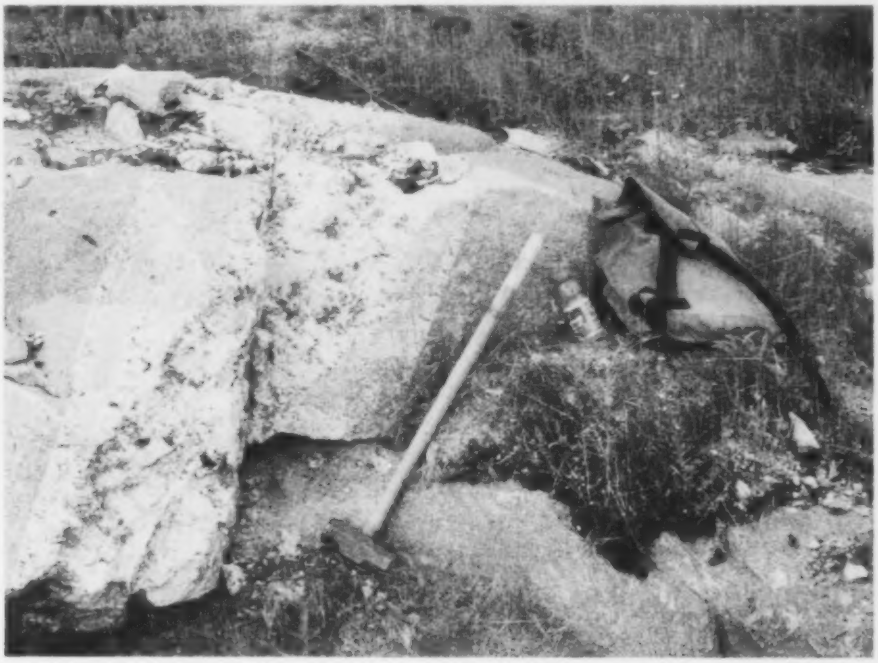

Photo 35. Muscovite potassic pegmatite dike cutting massive, biotite granite on Highway 17 in Way Township.

MINERALOGY OF BIOTITE GRANITE AND PEGMATITIC GRANITE

Most of the pink, biotite granites north of Hearst on Highway 583 (Casgrain and Hanlan townships) and on Fuschimi Road (Stoddart and Fuschimi townships) are chemically poorly evolved such that strongly peraluminous minerals are virtually absent except for rare muscovite. The garnet in granitic rocks of this area is generally almandine-dominant as found in biotite granite, biotite potassic pegmatite and biotite migmatitic metasedimentary rocks from north of Fontaine's Landing and along the Fuschimi Road. Here, magnesium-rich almandine contains pyrope (7 to 25%) and modest spessartine (3 to 14%).

North of Fontaine's Landing in Bannerman Township, however, primitive red garnets appear in biotite-bearing, migmatitic metasedimentary rocks as magnesium-rich almandine with greater than 20% pyrope. Such garnets occur at the contact between pink biotite granite or biotite potassic pegmatite with metasedimentary migmatite and in biotite lenses in granite. These are the most primitive garnets in the Hearst area. The magnesium-rich almandine is associated with magnesium-rich "biotite" (phlogopite-siderophyllite) with no rubidium or cesium detected by electron microprobe.

The most evolved garnet from the barren granites occurs in potassic pegmatite in the southeast part of Stoddard Township (*see* Figure 26, back pocket) at 02-JBS-06 (UTM 290143E 5512802N, Zone 17). The garnet, intermediate between almandine and spessartine, occurs in a white vein of apatite-biotite potassic pegmatite and contains a much more evolved level of the spessartine component (45 weight %). This particular outcrop is about 25 km northwest of the McCrea–Shetland fertile pegmatitic granite zone (*see* Figure 26, back pocket).

Green fluorapatite was documented at 3 pegmatitic granite localities (*see* Figure 26, back pocket). The most evolved fluorapatite (MnO: 2.06 to 2.28 weight %) was found in magnetite-bearing, muscovite potassic pegmatite along Highway 11, west of Nagagami River (02-FWB-04 in McCoig Township). The fluorapatite at the other 2 localities in potassic pegmatite (02-JBS-06 in Stoddart Township) and in biotite pegmatitic granite (02-FWB-67 in Elgie Township) contain very low MnO contents (0.05 to 0.40 weight %).

Only 5 blocky potassium feldspar compositions were obtained from pegmatitic granites in the Hearst–Bannerman area (*see* Tindle, Selway and Breaks 2006 (MRD 210), Table 5: Casgrain, Stoddart and Studholme townships) and indicate a low degree of magmatic evolution relative to fertile granites elsewhere in the Hearst area. Contents of Rb (mean = 275 ppm; range = 231 to 373 ppm) and Cs (mean = 5.32 ppm; range 1.74 to 14.3 ppm) typify those of poorly evolved granitic rocks as compared to fertile, more peraluminous granites found elsewhere in the Hearst area (e.g., McCrea–Shetland pegmatitic granite zone).

PETROCHEMISTRY OF BIOTITE GRANITE AND PEGMATITIC GRANITE

Twenty-seven bulk rock compositions of granitic rocks, interpreted as I-type and S-type in origin, which underlie an extensive area north and northwest of Hearst, are given in Table 8 (*see* Tindle, Selway and Breaks 2006 (MRD 210)). Both groups of granites and related pegmatitic granites are weakly peraluminous (I-type mean A/CNK = 1.060, range 0.998 to 1.106 versus S-type mean A/CNK = 1.085, range 1.030 to 1.291) and generally with higher K_2O relative to Na_2O. An exception to the latter is a pale pink albitite from 02-JBS-89-01 in Casgrain Township that contains 11.61 weight % Na_2O, similar to albitites encountered in the Separation Rapids pegmatite group (Breaks and Tindle 2002, p.172). However, the albitite at this locality is notably depleted in rare-elements and, therefore, has no economic significance.

Table 9. Summary of bulk rock compositions of internal units from the Lowther Township rare-element pegmatite.

Zone Sample #	Na_2O (ppm)	K_2O (ppm)	Be (ppm)	Cs (ppm)	Ga (ppm)	Li (ppm)	Nb (ppm)	Ta (ppm)	Rb (ppm)	Sn (ppm)	K/Cs	K/Rb
Parent granite												
02-JBS-11-40	4.81	0.77	3	9.7	14	41	5.3	15	49	N.D.	656	130
Sodic pegmatite wall zone												
02-JBS-11-16	6.95	0.63	5.4	112	36	211	39	7.4	295	12	47	17.7
Cleavelandite zone												
02-FWB-162	7.27	4.28	6	470	110	599	258	91	2872	79	75.6	12.4
02-JBS-11-20	5.32	6.67	4.8	534	134	1256	168	70	2584	73	88	18.2
02-JBS-11-32	3.85	8.9	4	472	83	3339	44	27	3069	40	156	24.1
Spodumene zone												
02-JBS-11-22	2.45	5.82	27	595	55	18 540	3.6	6.3	2135	14	81	22.6
02-JBS-11-26	2.63	2.73	38.5	261	104	18 672	15.4	15	927	41	87	24.5
Lepidolite pod												
02-JBS-11-35	4.40	6.64	9	592	117	10 050	70	41	5637	60	93	9.8

Notes:

02-JBS-40: Muscovite<biotite-plagioclase-quartz sodic pegmatite
02-JBS-11-16: Tourmaline-garnet-zinnwaldite sodic pegmatite
02-FWB-162: Muscovite-cleavelandite rock
02-JBS-11-20: Garnet-muscovite-cleavelandite rock
02-JBS-11-32: Garnet-spodumene-quartz<<cleavelandite rock
02-JBS-11-22: Quartz-potassium feldspar-spodumene rock
02-JBS-11-26: Muscovite-cleavelandite-spodumene rock
02-JBS-11-35: Quartz-lepidolite-cleavelandite rock

Both the I-type and S-type granites are notably depleted or similar in most of the rare-elements (Li, Be, Cs, Nb and Ta) relative to the average upper continental crust (Taylor and McLennan 1985). These granitic rocks are considerably depleted in Nb and Ta (I-type mean Ta= 0.48 ppm; S-type mean Ta = 0.50 ppm) such that mean values are about 25% that of the average upper continental crust. Thus, the granitic rocks of this area are not considered prospective for tantalum-niobium-enriched pegmatite deposits.

Fertile Peraluminous Pegmatitic Granites

Several scattered dikes and small masses, up to 30 by 100 m in size, of mineralogically more evolved pegmatitic granitic rocks were observed in unmigmatized metawacke of the Quetico Subprovince and in mafic metavolcanic rocks along the Quetico–Wawa subprovincial boundary zone (*see* Figure 27). These occurrences are distributed in 3 general areas (*see* Figure 26, back pocket):

- Pelletier Township pegmatitic granite zone (minimum 8 by 20 km area)
- McCrea–Shetland pegmatitic granite zone (minimum 5 by 40 km elongate area between McCrea Township and Shetland–Lowther townships)
- Pagwachuan River pegmatitic granite zone (minimum 18 by 50 km area)

The bulk rock and mineral chemical data (potassium feldspar and muscovite) that pertain to pegmatitic granites from these zones are given in Tables 5 and 8 (*see* Tindle, Selway and Breaks 2006 (MRD 210)). A summary of potassium feldspar and muscovite compositions of exploration significance from evolved, fertile pegmatitic granites is presented in Tables 9 and 10.

Table 10. Rubidium, cesium, K/Rb and K/Cs in potassium feldspar bulk compositions from pegmatitic granite and rare-element pegmatite of the Hearst area.

Sample #	Rb (ppm)	Cs (ppm)	K/Rb	K/Cs
Shetland Township pegmatitic granites				
02-FWB-64-01	697	17	158	6337
02-JBS-17-01	567	9	187	11806
02-JBS-17-03	853	78	126	1378
Pelletier Township pegmatitic granite zone				
02-FWB-62-01	1229	40	90	2747
02-JBS-13-03	862	52	134	2224
Pagwachuan River pegmatitic granite zone				
02-FWB-03-04	197	12	574	9673
02-FWB-06-05	517	18	207	5951
02-FWB-08-03	1038	61	116	1979
02-JBS-10-02 (Pagwa Quarry)	398	20	278	5540
Montcalm Creek Quarry pegmatitic granites				
02-JBS-01-01	483	19	221	5640
02-JBS-02-02	623	30	190	3940
Lowther Township complex-type, lepidolite-subtype pegmatite				
LT97KF-2, cleavelandite zone	3725	305	30	360
Parent granite, Lowther Township pegmatite				
02-JBS-11-12	3502	168	32.3	674
02-JBS-11-13	2974	337	35.7	315
02-JBS-11-21	3901	382	29.0	296
LT-97-KF-1 (quartz-rich pod)	1510	97	71	1111
LT-97-KF-3	971	82	133	1335
Mean	2572	213	60	746

Notes:

02-FWB-64-01: White blocky potassium feldspar in quartz-rich patch enclosed by biotite<<muscovite potassic pegmatite
02-JBS-17-01: White potassium feldspar from muscovite potassic pegmatite
02-JBS-17-03: White potassium feldspar from muscovite potassic pegmatite
02-FWB-62-01: White blocky potassium feldspar from quartz-rich patch in muscovite<biotite potassic pegmatite
02-JBS-13-03: White potassium feldspar from biotite-muscovite potassic pegmatite
02-FWB-03-04: Light pink potassium feldspar from biotite potassic pegmatite boudin concordant with layering in migmatitic metasedimentary rocks
02-FWB-06-05: White blocky potassium feldspar from tourmaline-biotite, muscovite pegmatitic leucogranite
02-FWB-08-03: Light orange potassium feldspar from quartz-rich patch in garnet-biotite potassic pegmatite
02-JBS-10-02: Light blue-grey blocky potassium feldspar muscovite potassic pegmatite
02-JBS-01-01: Pink potassium feldspar from coarse-grained, garnet-muscovite-biotite granite
02-JBS-02-01: Pink potassium feldspar from muscovite-biotite potassic pegmatite
LT-97-KF-2: Edge of a large, pink blocky potassium feldspar in contact with cleavelandite-rich zone
02-JBS-11-12: Pink potassium feldspar from muscovite-biotite sodic pegmatite
02-JBS-11-13: Pink potassium feldspar from muscovite-biotite sodic pegmatite
02-JBS-11-21: Pink potassium feldspar from muscovite-biotite sodic pegmatite
LT-97-KF-1: Pink blocky potassium feldspar from quartz-rich pod in parent pegmatitic granite, 100 m NW of Lowther Township pegmatite
LT-97-KF-3: Deep pink, potassium feldspar from magnetite-biotite pegmatitic granite

PELLETIER TOWNSHIP PEGMATITIC GRANITES

Dikes of pegmatitic granite intrude mafic metavolcanic rocks in the northern part of Pelletier Township, as exposed on the Prune Creek Road and adjacent logging roads within the Quetico–Wawa subprovincial boundary zone. These dikes, initially mapped by Berger (1985), range from 1 to 5 m in width, and consist of garnet-muscovite potassic pegmatite and garnet-muscovite fine-grained leucogranite, as at 02-FWB-09 (UTM 305498E 544892N, Zone 17) or sodic pegmatite as at 02-JBS-14 (UTM 305989E 5448581N, Zone 17). Black tourmaline sporadically occurs as intergrowths with quartz in a 5 m thick, garnet-muscovite potassic pegmatite at 02-FWB-09.

The 5 m thick pegmatite dike at 02-FWB-09 consists of interlayered garnet-muscovite fine-grained leucogranite and a coarser grained, garnet-muscovite potassic pegmatite. The garnet-muscovite potassic pegmatite contains accessory garnet, tourmaline, apatite and pyrite. Potassium feldspar contains Rb_2O (0.10 to 0.14 weight %) and Cs_2O up to 0.03 weight %. Dark red to dark orange garnet is mostly almandine with 27 to 32% spessartine. Black tourmaline-quartz graphic intergrowths, up to 2 by 4 cm, occur in the potassic pegmatite and the tourmaline has a composition of magnesium-bearing schorl. The fluorapatite contains moderate amounts of MnO (0.37 to 1.56 weight %).

Local metasomatism of the mafic metavolcanic host rocks is evident along the dike contacts by high concentrations of bronze biotite and minor black tourmaline. These metasomatic minerals have also been identified along the contacts of quartz veins in amphibolite, as identified in boulders at one pegmatite locality (02-FWB-09), and are thought to be associated with peraluminous granitic pegmatites. A biotite-bearing bulk sample, which contains 1.03 weight % K_2O, from a boulder at this locality also revealed anomalous Li (439 ppm), Rb (108 ppm), Cs (93 ppm), and evolved K/Rb (79) and K/Cs (92) ratios (*see* Tindle, Selway and Breaks 2006 (MRD 210), Table 8).

A green muscovite-rich, sodic pegmatite dike (12 to 50 cm wide) at 02-JBS-14 is hosted in pillowed metavolcanic rocks that contain local calc-silicate pods. The pillows are flattened and lenticular and metamorphosed to amphibolite facies. Biotite, tourmaline, hornblende and garnet occur in pillow selvages. The garnet is a calcium- and magnesium-rich almandine with 62 to 64% almandine.

This sodic pegmatite dike contains abundant green muscovite, potassium feldspar, quartz and minor molybdenite and small miarolitic cavities (2 cm) lined with muscovite and quartz. Two bulk rock analyses of this dike (*see* Tindle, Selway and Breaks 2006 (MRD 210), Table 8) indicate $Na_2O>K_2O$, slight enrichment of Mo (18 and 151 ppm) and modestly evolved K/Rb ratios (105 and 121).

Pegmatitic granites were also noted in layered migmatitic metasedimentary rocks of the Quetico Subprovince to the south of the narrow mafic metavolcanic belt mapped by Berger (1985). These granites are generally concordant to host-rock foliation and comprise 1 to 3 m wide dikes, which are deformed by boudinage and open folding. The granites consist of mostly white, biotite pegmatitic leucogranite and biotite potassic pegmatite with minor garnet-biotite granite and biotite-muscovite potassic pegmatite.

The degree of chemical evolution in granitic pegmatites situated in the southern part of Pelletier Township in generally low as assessed by bulk rock K/Rb (240 to 385: *see* Tindle, Selway and Breaks 2006 (MRD 210), Table 8), although fertile pegmatitic granite units were locally recognized as at 02-FWB-62. Here, muscovite potassic pegmatite, which grades into quartz-rich patches, is modestly evolved as indicated by the composition of blocky potassium feldspar. Elevated Rb (1229 ppm) and Cs (40 ppm) and significantly low K/Rb (89) and K/Cs (2223) are comparable to values found in potassium feldspar from the northern part of the fertile Separation Rapids pluton (Breaks, Selway and Tindle 2005). This observation provides support for the interpreted genetic linkage between fertile pegmatitic granites and migmatitic metasedimentary rocks of the Quetico Subprovince.

MCCREA–SHETLAND PEGMATITIC GRANITE ZONE

The McCrea–Shetland pegmatitic granite zone (*see* Figure 26, back pocket) is characterized by aplite zones, albitized potassic pegmatite, sodic pegmatite dikes and small masses of pegmatitic granite, one of which in Lowther Township is a parent mass to a complex-type, rare-element pegmatite. This 5 by 40 km zone consists of 4 areas from east to west with increasing degree of fractionation and is open to the west:

1. aplite-pegmatite layered, muscovite pegmatite dike system with minor tourmaline exposed in the Montcalm Creek quarry in McCrea Township (02-JBS-01 and 02-JBS-02: UTM 358384E 5489675N, Zone 17)
2. biotite-muscovite sodic pegmatite in Shetland Township mineralized with ferrocolumbite and ferrotantalite (02-JBS-16: UTM 312061E 5486226N, Zone 17)
3. muscovite pegmatitic granite mass in Shetland Township (02-JBS-17 and 02-FWB-64)
4. the Lowther Township complex-type, lepidolite-subtype, rare-element pegmatite (02-JBS-11: UTM 302704E 5485788N, Zone 17)

MONTCALM CREEK QUARRY PEGMATITIC GRANITES

The Montcalm Creek quarry on Highway 11, east of Hearst in McCrea Township, consists of 2 large pits. The first pit next to a pond (02-JBS-01: UTM 358384E 5489675N, Zone 17) consists of biotite granite with coarse-grained, graphic, pink, potassium feldspar (up to 26 cm long), quartz, bladed biotite and minor silver muscovite, fine-grained red garnet, and garnet altered to biotite. The metasedimentary host rock is rich in biotite along the contact with the biotite granite. The garnet in the biotite granite is almandine with subordinate spessartine (32 to 37 weight %), that has locally altered to biotite.

The second pit in the bush near Montcalm Creek (02-JBS-02) contains rocks more evolved than the first pit and consists of potassic pegmatite with a pod of coarse-grained pink potassium feldspar (up to 40 cm long) and quartz. The potassic pegmatite contains coarse-grained, silver muscovite up to 9 cm across. The second pit also hosts a layered vein with a fine-grained, garnet-tourmaline-green muscovite aplite layer, a coarse quartz core and a muscovite leucogranite layer.

There are highly depleted levels of the rare earth elements (REE) (total REE = 18 ppm: *see* Tindle, Selway and Breaks 2006 (MRD 210), Table 8) in the aplite layer, relative to the average upper continental crust (Taylor and McLennan 1985). Depletion of the REE is a characteristic petrochemical feature of fertile granites and is exemplified elsewhere as in the Dryden area (Breaks and Moore 1992, p.806) and in southeast Manitoba (Černý and Meintzer 1988).

The pegmatitic granites in the second pit intrude fine-grained, biotite-rich metasedimentary rocks. A thin section of the rock reveals aligned biotite crystals, quartz, plagioclase and minor opaques. The "biotite" is actually phlogopite-siderophyllite with low contents of Rb_2O (up to 0.08 weight %) and Cs_2O (up to 0.08 weight %).

The muscovite aplite layer contains minor fine-grained red garnet and rare blue and green apatite and pyrite. In thin section, the major minerals are muscovite, plagioclase strongly altered to sericite, quartz and microcline with minor sulphides, calcite, chlorite and garnet.

The garnet is magnesium-bearing almandine and intermediate spessartine-almandine (48 to 50% spessartine). The fluorapatite contains moderate amounts of MnO (0.25 to 1.94 weight %).

The muscovite leucogranite layer contains coarse-grained green muscovite, white potassium feldspar and minor garnet. In thin section, the muscovite leucogranite contains quartz, plagioclase and microcline altered to sericite, and minor chlorite and garnet. The muscovite leucogranite layer contains magnesium-bearing almandine (with 28 to 41% spessartine) distributed along the contact with the metasedimentary host rock. The blue fluorapatite contains minor amounts of MnO (0.17 to 0.31 weight %).

Bulk composition of the aplite (02-JBS-02-05: *see* Tindle, Selway and Breaks 2006 (MRD 210), Table 8) indicates a strongly peraluminous composition (A/CNK = 1.329). Relative to the average upper continental crust (Taylor and McLennan 1985), the aplite has slight enrichment in Cs (5.7 ppm), Ta (5.7 ppm) and Be (5.1 ppm) and a notable fractionation of Ta relative to Nb (Nb/Ta = 2.01). Such data are modestly higher than in the barren granites and pegmatitic granites described to the north and northwest of Hearst and imply the presence of fertile pegmatitic granites in the area.

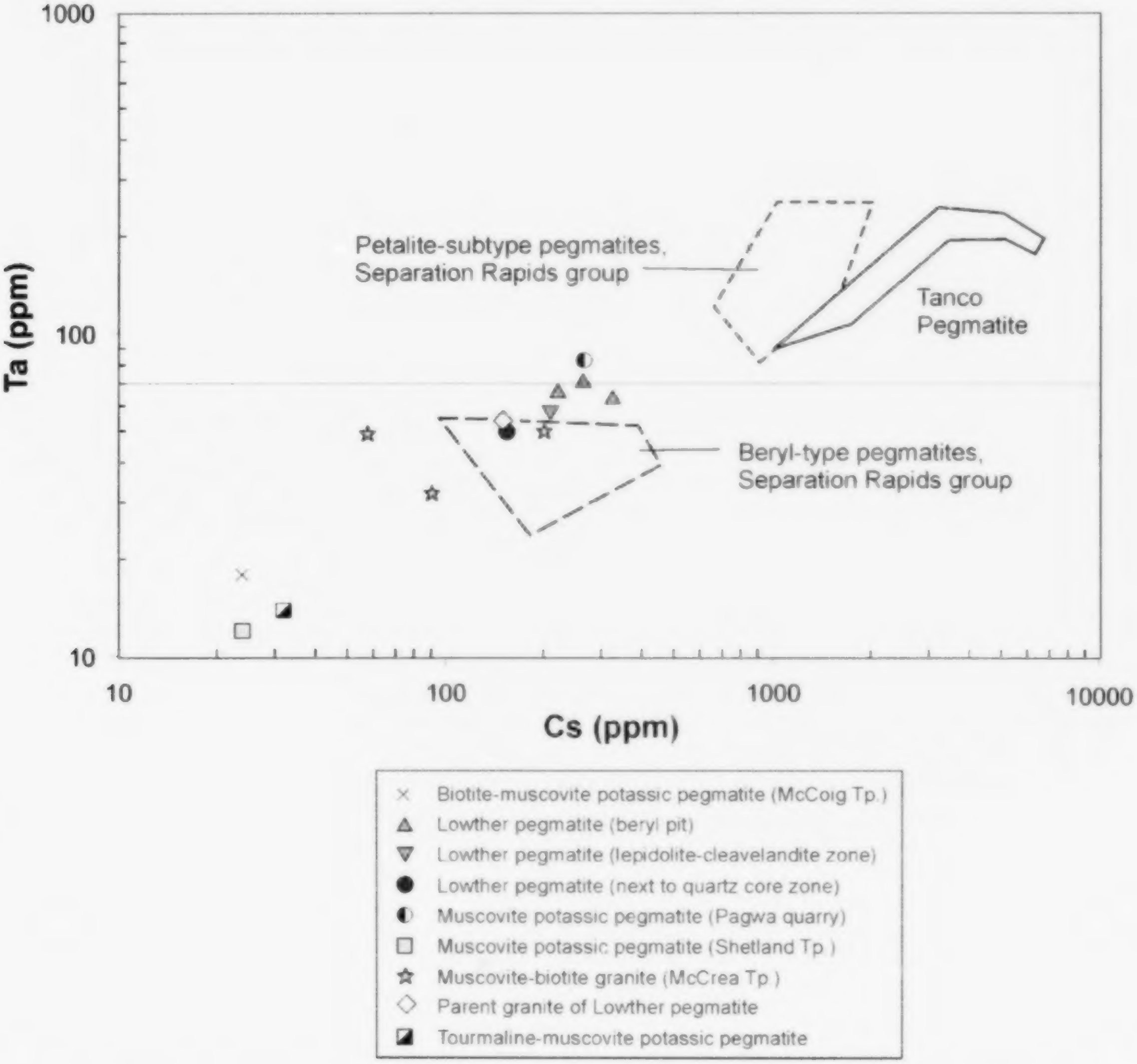

Figure 28. Cesium versus tantalum (ppm) in muscovite from pegmatitic granites and rare-element pegmatite from the Hearst area. Fields of variation for the Separation Rapids pegmatite group (beryl-type and petalite-subtype) from unpublished data of the authors. The Tanco pegmatite field is *from* Morteani and Gaupp (1989).

The muscovite bulk composition data are summarized in Table 10 and reveal that the abundance ranges for beryllium, cesium, niobium and tantalum from the Montcalm Creek quarry overlap with those from the Lowther Township pegmatite, thus, supporting the inference of the fertile status of the constituent pegmatitic granites. The cesium versus tantalum diagram (Figure 28) indicates that muscovite bulk compositions from these pegmatites are similar to those found in beryl-type pegmatites elsewhere in the Superior Province of Ontario such as from the Separation Rapids pegmatite group (Breaks and Tindle 2002).

SHETLAND TOWNSHIP FERTILE PEGMATITIC GRANITES

Rare-element mineralization was discovered during this survey at 02-JBS-16 (UTM 312061E 5486226N, Zone 17) in Shetland Township in a 3 m wide dike of garnet-biotite-muscovite sodic pegmatite that intrudes foliated, unmigmatized biotite metawacke. The dike is an albite-rich, muscovite pegmatite in which most of the potassium feldspar has been albitized. Minor, fine-grained, red garnet and rare green to blue fluorapatite and opaque oxide minerals are subtly present in hand specimen.

A thin section of the fine-grained metawacke reveals aligned chlorite, feldspar altering to saussurite, quartz and minor biotite. The fluorapatite along the apatite-rich contact zone between the metawacke host rock and the sodic pegmatite is MnO poor (0.03 to 0.18 weight %) and is associated with brown Rb_2O poor (up to 0.07 weight %) and Cs_2O-poor muscovite (and up to 0.06 weight %).

A large bulk sample of the garnet-biotite-muscovite sodic pegmatite dike (02-JBS-16-02: *see* Tindle, Selway and Breaks 2006 (MRD 210), Table 8) reveals anomalous concentrations of Rb (501 ppm), Be (98 ppm), Ta (113 ppm), Nb (82 ppm), Ga (29 ppm) and Sn (18 ppm). The rock also has high Na_2O (8.63 weight %), and much lower K_2O (1.66 weight %) and CaO (0.24 weight %). Very low Nb/Ta (0.72), K/Rb (27), K/Ba (363) and Rb/Sr (9) ratios suggest considerable chemical evolution from the source magma composition.

This garnet-biotite-muscovite sodic pegmatite also contains ferrocolumbite and ferrotantalite with patchy zoning and occasional oscillatory zoning. The ferrocolumbite (24.4 to 51.4 weight % Ta_2O_5) and the ferrotantalite (53.1 to 68.5 weight % Ta_2O_5) are iron rich with a narrow range in manganese and iron content but with a large range of Mn/(Mn+Fe) as shown in Figure 29.

The red garnet in the garnet-biotite-muscovite sodic pegmatite is zoned with spessartine enriched in the cores (49 to 73%) and almandine enriched in the rims (49 to 54%). The fluorapatite in the garnet-muscovite sodic pegmatite is also MnO rich (1.79 to 4.10 weight %). The muscovite contains moderate Rb_2O (0.26 to 0.63 weight %) and Cs_2O (0.01 to 0.04 weight %).

The garnet and muscovite compositions from 02-JBS-16 overlap, coupled with those of the Lowther Township pegmatite, suggest that the 2 localities, less than 10 km apart, are genetically related to a sodium-rich, peraluminous pegmatitic granitic magma source.

The sodic pegmatite dike at 02-JBS-16 could have been derived from the larger pegmatitic granite mass situated 1 km north at 02-JBS-17 (UTM 311660E 5487245N, Zone 17). A white, biotite<<muscovite potassic pegmatitic granite mass (60 by 100 m) contains white, blocky potassium feldspar (up to 17 cm long) and coarse-grained silver and brown muscovite (up to 7 cm across). The muscovite potassic pegmatitic granite intrudes earlier medium-grained muscovite-biotite granite.

Two bulk rock compositions of potassic pegmatite (02-FWB-64-02) and medium-grained granite (02-JBS-17-04) units from this pegmatitic granite mass (*see* Tindle, Selway and Breaks 2006 (MRD 210), Table 8) reveal a more primitive chemistry relative to the pegmatite dike at 02-JBS-16. Only modestly anomalous Rb contents (190 and 299 ppm: *see* Tindle, Selway and Breaks 2006 (MRD 210), Table 8) were noted amongst the various rare elements relative to the average upper continental crust of 112 ppm (Taylor and McLennan 1985). Further, a substantially depleted total REE content of 13 ppm was documented in the potassic pegmatite unit, a characteristic chemical feature of evolved peraluminous granites (Černý and Meintzer 1988).

Blocky potassium feldspar compositions isolated in sporadic quartz-rich patches (*see* Table 10: 02-FWB-64-01) indicate the most fractionated part of the pegmatitic granite mass, as shown by the modest enrichment in Rb (697 to 853 ppm) and Cs (17 to 78 ppm) and by diminished ratios K/Rb (126 to 187) and K/Cs (1378 to 11 806). One bulk muscovite composition (*see* Table 11: 02-JBS-17-02) also supports the modest chemical evolution of the pegmatitic granite with higher Li, Sn and lower Be, Cs and Ta than that from the Montcalm Creek quarry.

A zoned pegmatite dike, hosted in tonalite in Orkney Township (UTM 315247E 5468096N, Zone 17) at 02-JBS-15 (*see* Figure 26, back pocket) contains a magnetite-biotite aplite wall zone and garnet-biotite potassic pegmatite core zone. Bulk composition of the aplite unit (*see* Tindle, Selway and Breaks 2006 (MRD 210), Table 8) reveals a primitive chemistry relative to S-type pegmatitic granites in the area as indicated by high K/Rb (373) and depletion of the various rare elements. This zoned dike is of uncertain magmatic affiliation. The fine-grained orange-red garnet from the potassic pegmatite core zone is enriched in spessartine (53 to 55%) relative to almandine (39 to 41%) that is more typical of S-type peraluminous granitic rocks found elsewhere in the area. However, magnetite is typically absent in the vast majority of S-type, peraluminous pegmatitic granites documented in the Superior Province of Ontario (Breaks and Bond 1993).

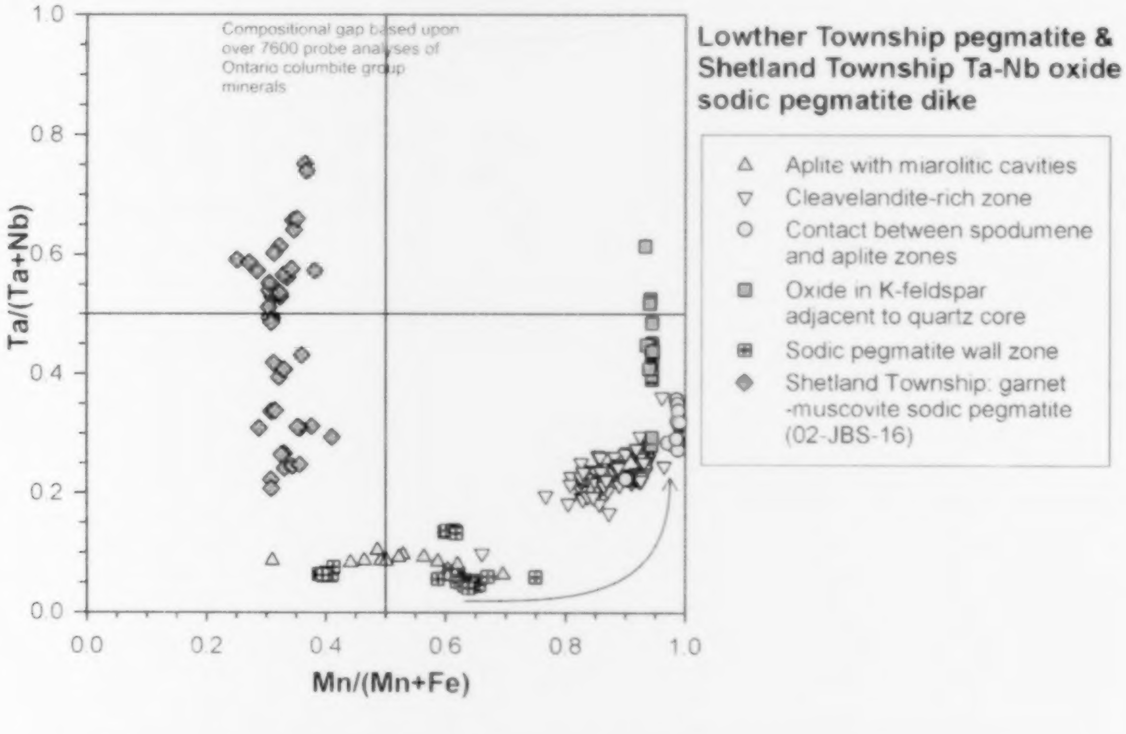

Figure 29. Columbite-tantalite quadrilateral plot (atomic ratios) for the Lowther Township complex-type pegmatite and the Shetland Township beryl-type pegmatite. Compositional gap between ferrotapiolite and ferrotantalite is based upon 7600 compositions of columbite-tantalite from Ontario. Microlite compositions may plot within this compositional space. Curved line (lower right of figure) gives fractionation trend for complex-type, lepidolite-subtype pegmatites (*after* Černý 1989, p.232).

LOWTHER TOWNSHIP PEGMATITE

Lithium-rich, rare-element mineralization in the Hearst area is only known at the Lowther Township pegmatite (*see* Figure 27; Photo 36). The Lowther Township pegmatite was discovered in 1939 by A. Villeneuve of Hearst when stripping and excavation of several shallow blast pits were undertaken (M.E. Hurst, Ontario Department of Mines, unpublished report, 1939). A later property examination was made by S.A. Ferguson in 1955 when the property was owned by I. Topaloff of Hearst (S.A. Ferguson, Ontario Department of Mines, unpublished report, 1955).

Emplacement of the pegmatitic granite parent mass surrounding Lowther Township pegmatite at the metamorphic transition is interpreted to be post-metamorphic as the pluton is undeformed and not recrystallized. The Lowther Township rare-element pegmatite (UTM 302704E 5485788N, Zone 17) occurs within the metamorphic transition between medium- and high-grade metasedimentary rocks (*see* Figure 27) in this part of the Quetico Subprovince.

Rare-element mineralization at the Lowther Township pegmatite is only the second example in the Quetico Subprovince hosted by its fertile, parent granite pluton. Elsewhere, this genetic relationship is only known at the MNW stock where a complex-type, petalite-subtype pegmatite is hosted (Breaks, Selway and Tindle 2003b). The Hearst area occurrences are situated within the central part of the Quetico Subprovince, similar to rare-element localities examined at Wisa Lake (Breaks, Selway and Tindle 2003a) and in the Georgia Lake area (Pye 1965; Breaks, Selway and Tindle 2003b).

The Lowther Township pegmatite is a lens-shaped body, 3.7 to 11 m in width over a minimum length of 110 m, in which the long axis of the pegmatite is oriented at 110°. The pegmatite lens was previously explored by 4 blast pits over 50 m strike length of the pegmatite where it has the greatest width (*see* Photo 36).

Photo 36. View of Lowther Township pegmatite looking west, partially stripped in 2002, and showing old blast pits now filled with water.

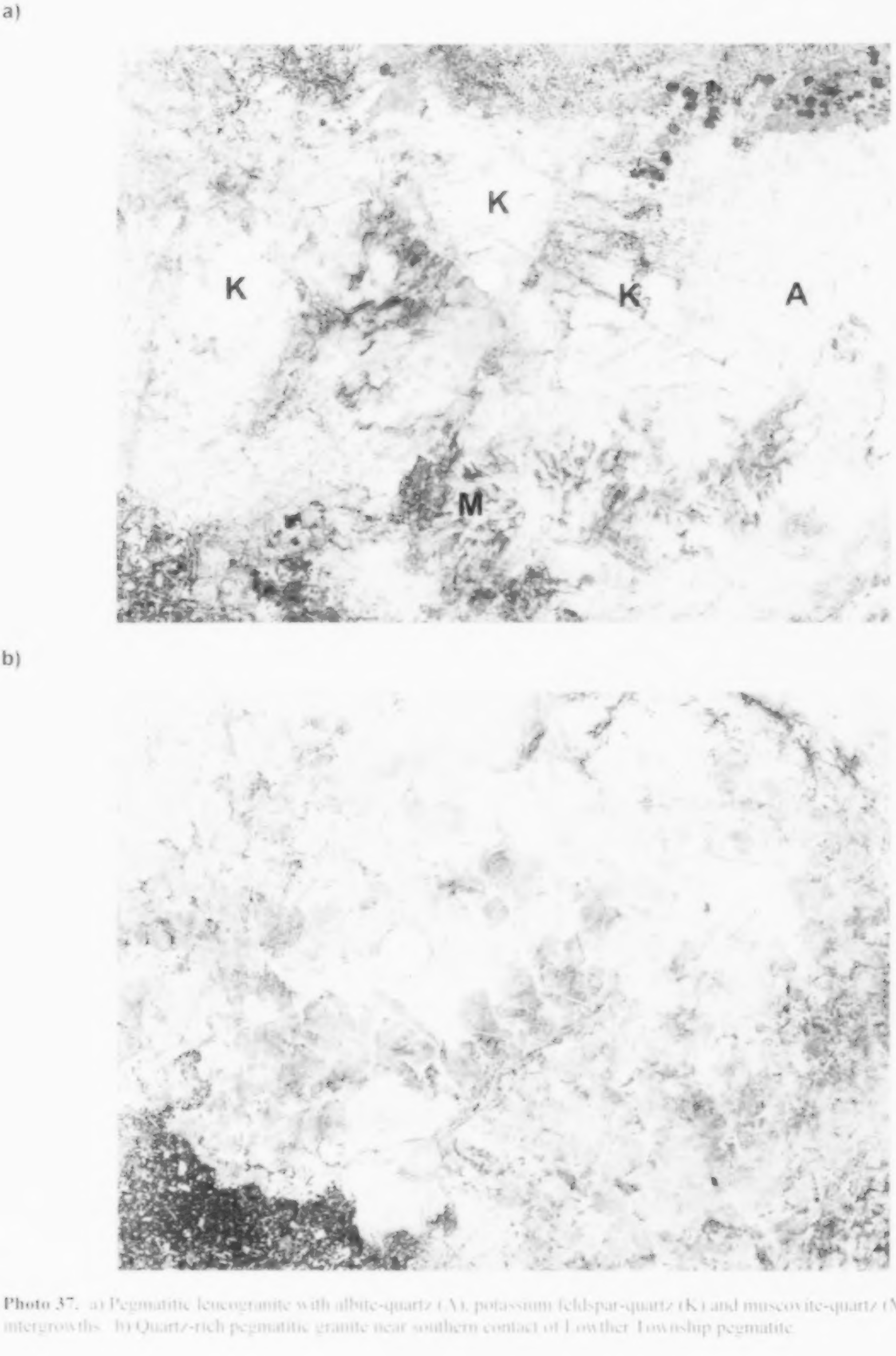

Photo 37. a) Pegmatitic leucogranite with albite-quartz (A), potassium feldspar-quartz (K) and muscovite-quartz (M) intergrowths. b) Quartz-rich pegmatitic granite near southern contact of Lowther Township pegmatite.

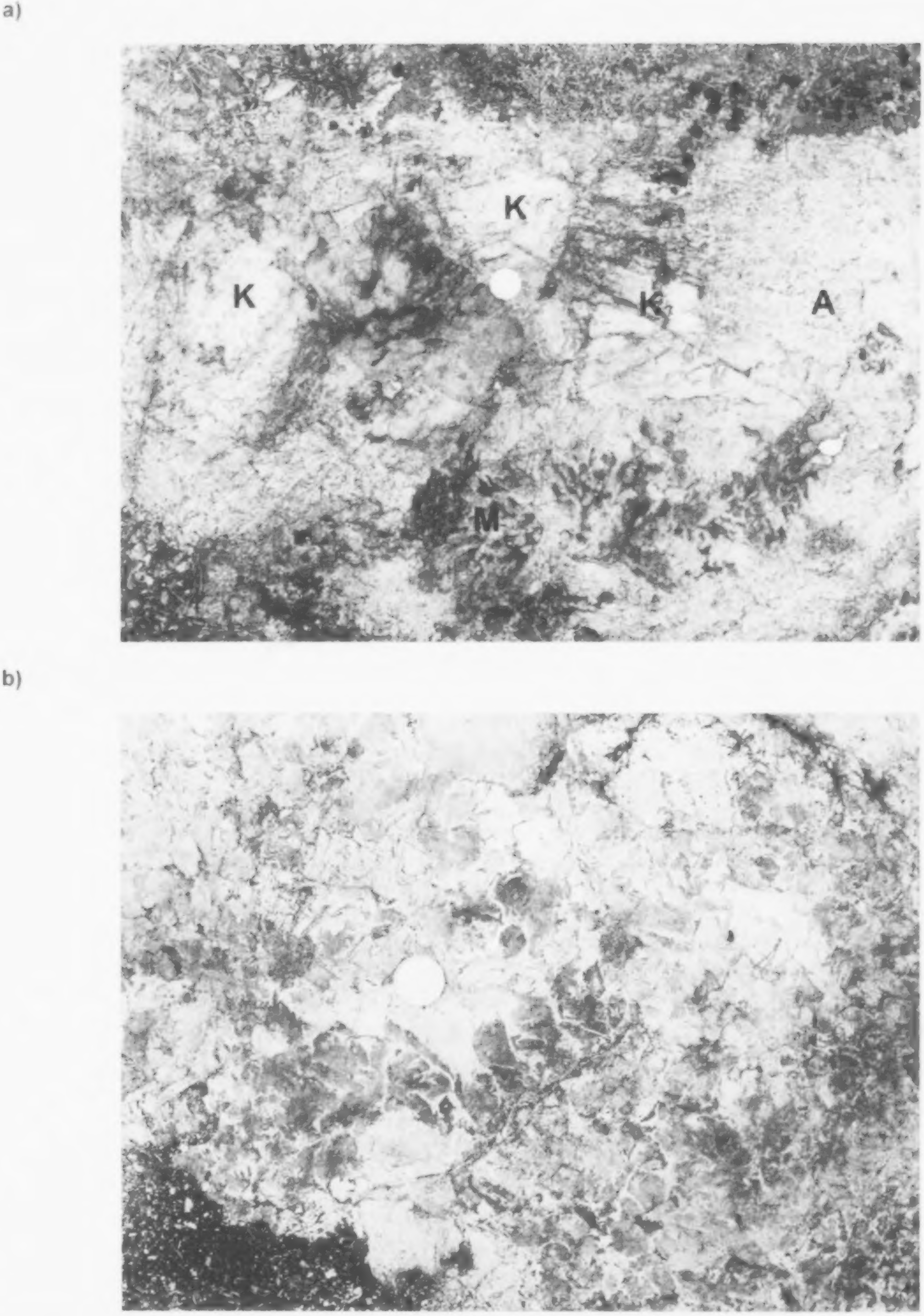

Photo 37. a) Pegmatitic leucogranite with albite-quartz (A), potassium feldspar-quartz (K) and muscovite-quartz (M) intergrowths. b) Quartz-rich pegmatitic granite near southern contact of Lowther Township pegmatite.

The pegmatite is enclosed in a north-tapering, parent mass of garnet-biotite pegmatitic leucogranite that is locally enriched in Na_2O (4.81 weight %) and SiO_2 (83.06 weight %) proximal to the pegmatite. There is a gradational contact between the sodic wall zone of the Lowther Township pegmatite and its parent granite. The parent granite near the southern gradational contact of the pegmatite consists of an albite-quartz-rich rock that texturally varies from graphic masses of quartz and albite to coalesced quartz phenocrysts with interstitial albite (Photos 37a and 37b). Elsewhere, the parent granite mostly consists of garnet-biotite pegmatitic leucogranite with gradational, local quartz-rich pods that host pink to white, perthitic potassium feldspar, coarse-grained, green muscovite books (up to 5.5 cm across), and minor black tourmaline and orange-red garnet. The pegmatitic granite is enclosed within massive biotite-hornblende diorite.

Age of emplacement of the Lowther Township and its parent granite is estimated at 2627±12 Ma based upon laser ablation inductively coupled plasma mass spectrometry (LA-ICP–MS) dating of a manganocolumbite grain from the pegmatite (F.W. Breaks, OGS, unpublished data, 2006). Metamorphism and partial melting of metasedimentary rocks and consequent generation of peraluminous magmatic rocks was established at 2670±2 Ma (Percival and Sullivan 1988). A later event of probable I-type granitic magmatism in the subprovince led to emplacement of magnetite-biotite granite at 2665±2 Ma and postdated by massive granitic pegmatite at 2653+3/–4 Ma (Percival and Sullivan 1988).

The Lowther Township pegmatite is classified as a lepidolite-subtype pegmatite because of the following attributes:

- dominance of sodium-rich bulk compositions: $Na_2O >> K_2O$ in most analyses, as cleavelandite and aplite units are abundant (Černý 1989). Lepidolite-subtype pegmatites typically have a greater abundance of albite relative to potassium feldspar in the innermost pegmatite zones
- trend of the Ta-Nb oxide minerals in the Lowther Township pegmatite matches the characteristic trend for oxides in lepidolite-subtype pegmatites in the columbite-tantalite quadrilateral plot (Černý 1989)
- manganese enrichment in bulk compositions and specific minerals, i.e., manganotantalite, spessartine, and lepidolite

Lepidolite-subtype pegmatites have a greater abundance of albite relative to potassium feldspar in the innermost pegmatite zones, whereas spodumene-subtype pegmatites have the opposite modal feature (Selway et al. 1999; Breaks, Selway and Tindle 2003a). The pegmatite is complexly zoned with 6 internal units as listed below, from the outermost part to the inner core. The pegmatite was not mapped in detail as considerable stripping would be required to completely expose the internal zonal configuration (*see* Photo 36). Alternatively, various photographs below will give impressions of most units:

1. sodic pegmatite wall zone
2. aplite zone
3. spodumene zone
4. cleavelandite-rich zone with local coarse-grained beryl
5. lepidolite-cleavelandite pod
6. quartz-rich core with green muscovite and minor spessartine and black tourmaline

The **sodic pegmatite wall zone** is generally about 1 m thick and is gradational into its muscovite-biotite parent pegmatitic granite (Photo 38). The wall zone unit consists of coarse, pink to white cleavelandite, coarse-grained quartz, and mica-rich pods composed mostly of radiating, green zinnwaldite up to 2 cm diameter, and minor fine-grained, red garnet, Ta-Nb oxide minerals and graphic black tourmaline. The cleavelandite ($Ab_{91}An_8Or_1$) commonly has an orange staining and typically reveals an iridescence (peristerite texture). The zinnwaldite-rich pods contain a core of a red-brown weathered mineral that consists of pyrite almost completely altered to hematite. The green mica-rich pods consist of lithian muscovite to zinnwaldite that is enriched in Rb_2O (0.33 to 1.04 weight %), Cs_2O (0.12 to 1.29 weight %), MnO (0.26 to 0.76 weight %) and zinnwaldite with overlapping levels of Rb_2O (0.26 to 0.71 weight %), Cs_2O (0.09 to 1.22 weight %), and MnO (0.98 to1.27 weight %). Zircon is sporadically present as black inclusions in spessartine.

The **aplite zone** is dominated by fine-grained, cleavelandite blades with interstitial green muscovite, quartz, orange spessartine, sparse brown zircon (up to 1 cm with radiation halos) and pyrite cubes partially replaced by hematite. This unit exhibits a ragged contact with the adjacent spodumene zone, marked by embayments of cleavelandite-rich masses projecting into the spodumene-potassium feldspar-quartz assemblage. Local manganocolumbite grains and miarolitic cavities up to 1 cm diameter occur in proximity to this contact.

The **spodumene pegmatite zone** was only found in small patches near the westernmost two blast pits. This unit consists of a randomly oriented, box-work texture of pink and green spodumene blades with interstitial, white potassium feldspar and quartz. Local zircon occurs as dark brown grains with radiation halos.

The **cleavelandite-rich zone** forms interconnected embayments within the outer parts of the quartz-rich core zone (Photo 39). The mineralogy is characterized by abundant, coarse-grained cleavelandite (up to 90 volume %) and interstitial, fine-grained, green muscovite (up to 10 volume %), orange spessartine (locally up to 6 mm diameter and 30 volume %; Photos 40a and 40b), and minor pink spodumene and manganocolumbite, dark brown sphalerite and tournaline inclusions within spessartine.

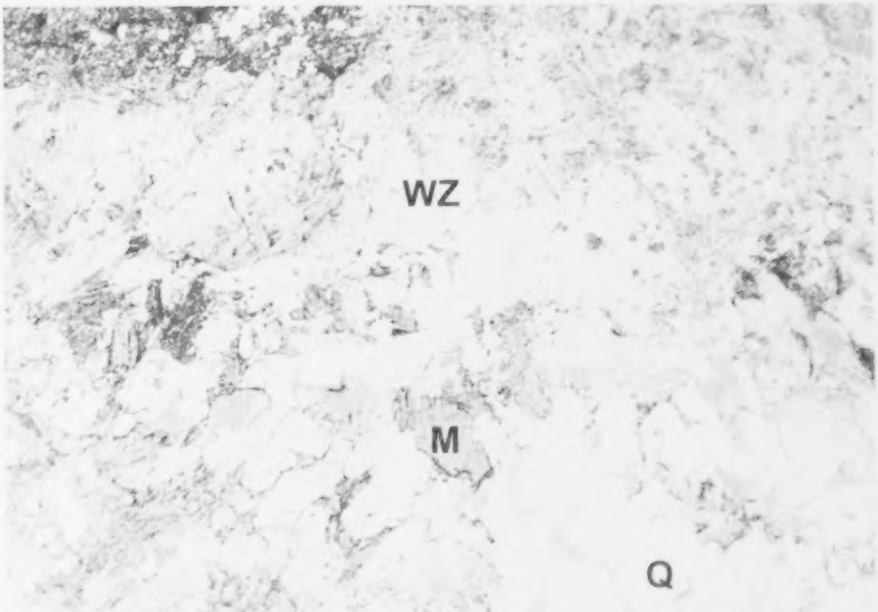

Photo 38. Sodic pegmatite wall zone (WZ) that grades into the quartz-rich core zone (Q). Coarse muscovite books (M) are common along contact between the zones. Dark spots in the wall zone consist of zinnwaldite-rich nodules.

mineral that consists of pyrite almost completely altered to hematite. The green mica-rich pods consist of lithian muscovite to zinnwaldite that is enriched in Rb_2O (0.33 to 1.04 weight %), Cs_2O (0.12 to 1.29 weight %), MnO (0.26 to 0.76 weight %) and zinnwaldite with overlapping levels of Rb_2O (0.26 to 0.71 weight %), Cs_2O (0.09 to 1.22 weight %), and MnO (0.98 to1.27 weight %). Zircon is sporadically present as black inclusions in spessartine.

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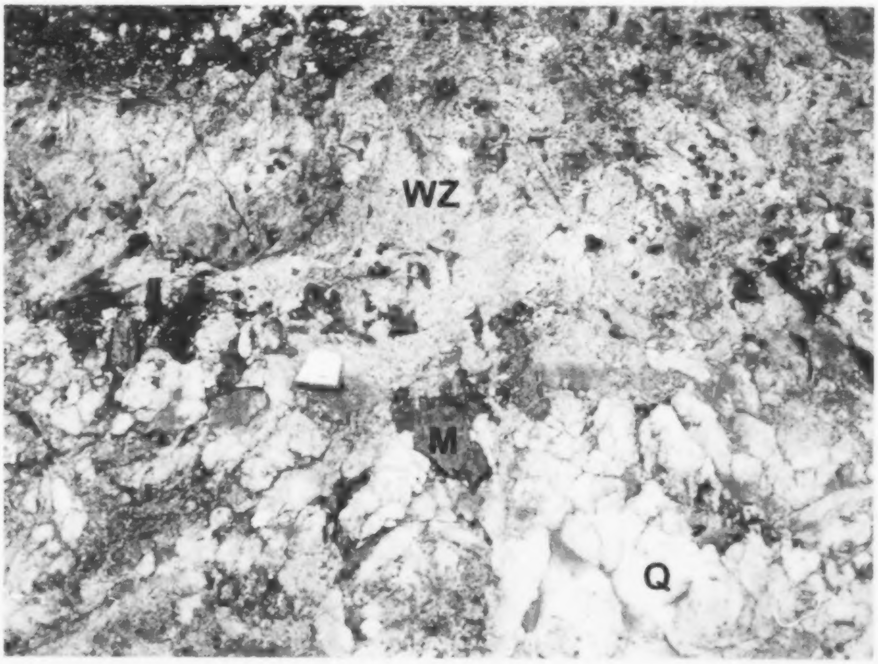


Photo 38. Sodic pegmatite wall zone (WZ) that grades into the quartz-rich core zone (Q). Coarse muscovite books (M) are common along contact between the zones. Dark spots in the wall zone consist of zinnwaldite-rich nodules.

A large, colour zoned beryl crystal (20 by 36 cm), conspicuous by its pink core and light green rim, lies in contact with a mass of grey quartz and, thus, appears part of the quartz-rich core zone (Photo 41). An irregular contact between cleavelandite-rich zone and the zoned beryl crystal provides evidence of albitization (*see* Photo 41). Cleavelandite blades were also noted to overprint parts of the large beryl including its crystal surfaces. Green muscovite books (up to 13 by 4.5 cm), orange spessartine (up to 6 mm), minor black tourmaline (7 to 8 mm) inclusions and cleavelandite occur next to the quartz core. Sparse, dark brown sphalerite occurs between cleavelandite blades.

The **quartz-lepidolite-cleavelandite unit** is confined to a single, ovoid, 15 to 30 by 110 cm pod that is completely enveloped by the quartz core (Photo 42). This conspicuous unit contains abundant cleavelandite (50 volume %) and purple lepidolite (40 volume %), with minor quartz (10 volume %) and sparse black oxide minerals that were not analyzed.

The **quartz-rich core zone** comprises massive, white to grey, quartz and local pods rich in cleavelandite, orange spessartine and muscovite. Large megacrysts of quartz, up to 40 by 63 cm, occur isolated in the adjacent cleavelandite-rich unit (*see* Photos 40a and 40b).

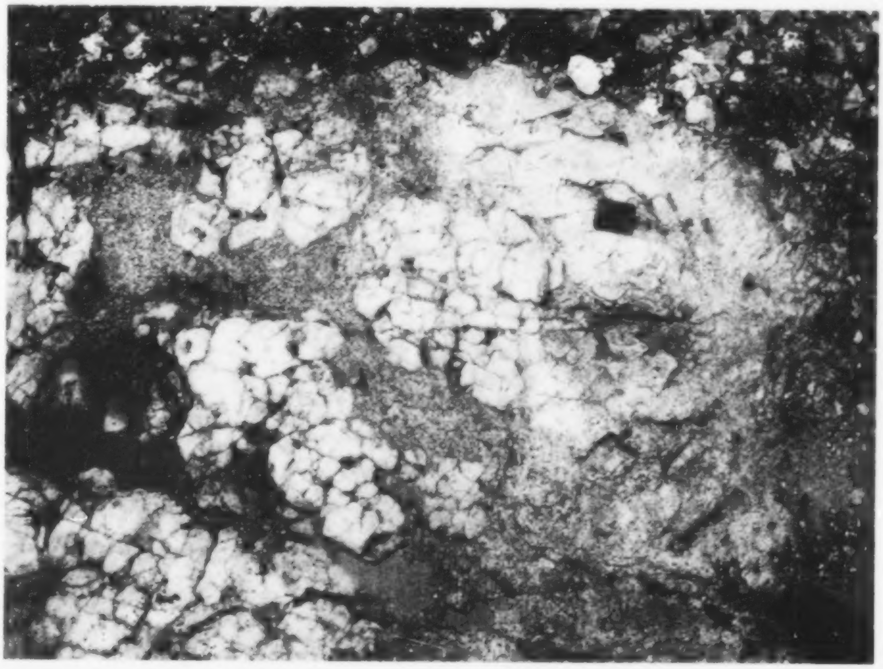


Photo 39. Stained slab revealing spodumene-potassium feldspar zone (S) enveloped by cleavelandite-rich replacement masses (C).

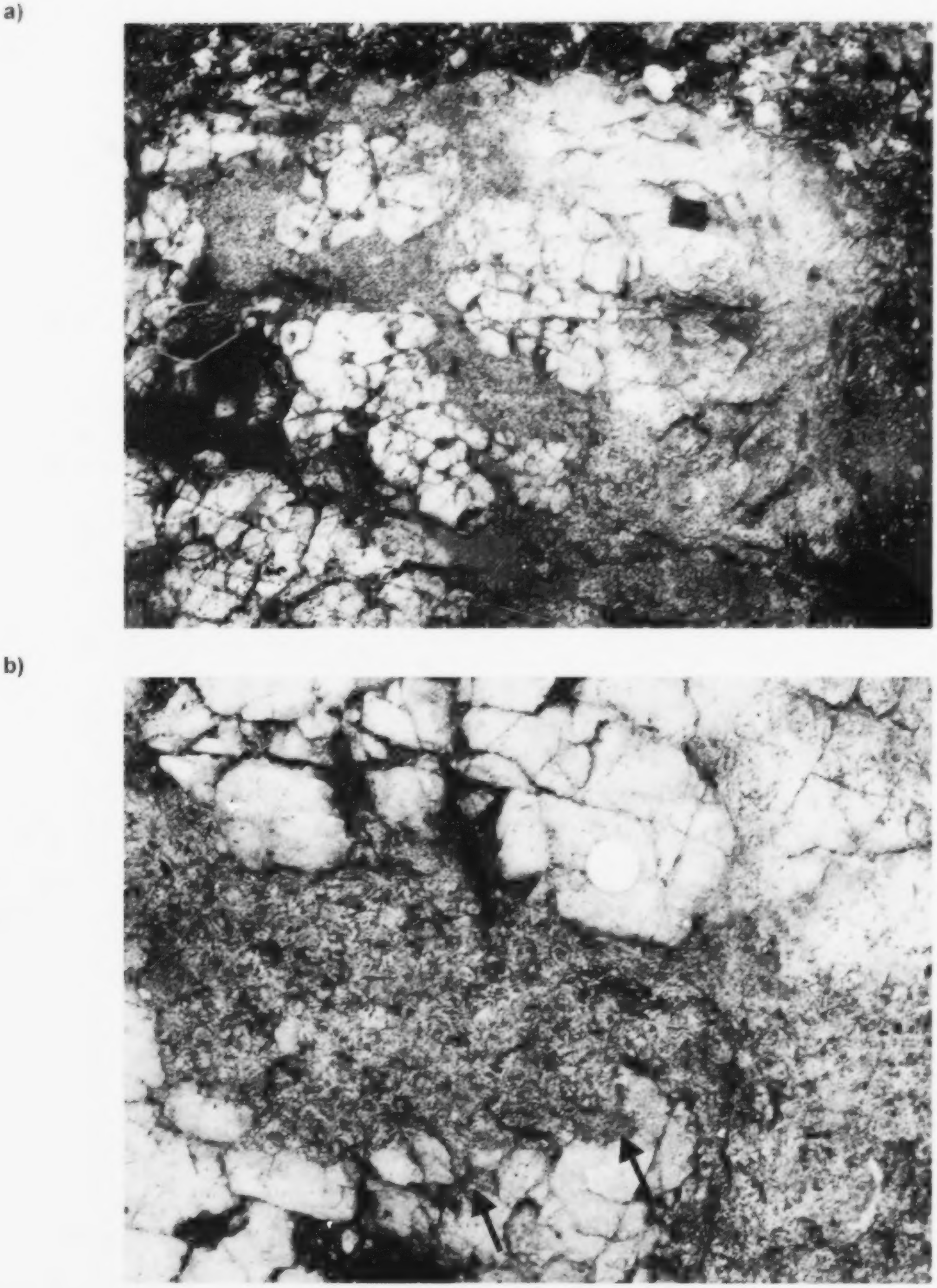


Photo 40. a) Cleavelandite zone with embayments into the quartz-rich core zone. b) Close-up of cleavelandite-rich material with abundance of orange spessartine garnet that overgrows quartz (indicated by arrows).

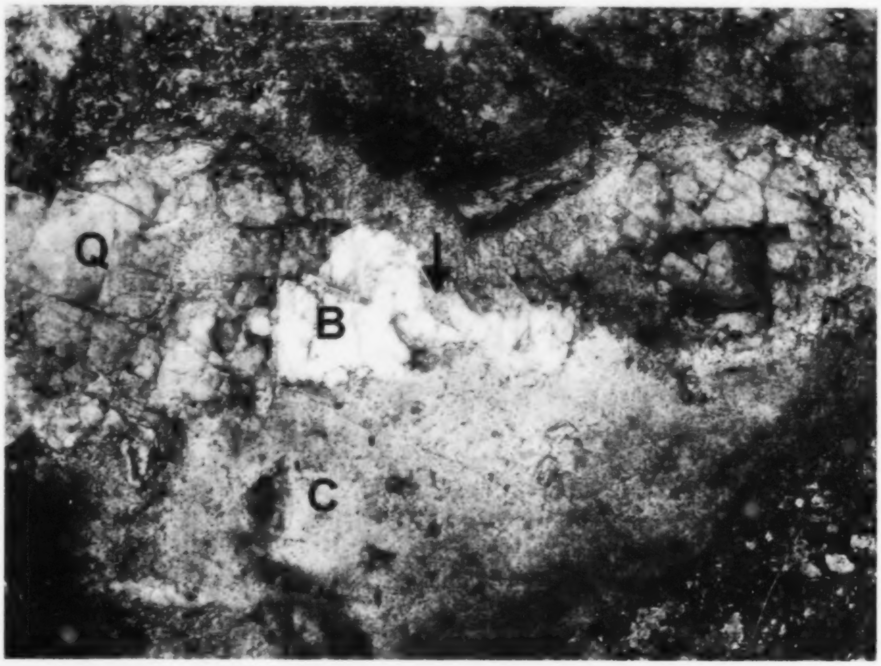


Photo 41. Ragged crystal remnant of colour zoned beryl (B) with surviving crystal face in contact with quartz-rich mass (Q) to left of coin. The beryl-quartz assemblage is entirely enveloped by cleavelandite-rich masses (C). Arrow points to replacement embayment of cleavelandite into beryl.

Photo 42. Lepidolite-albite pod completely enveloped by the quartz-rich core zone.

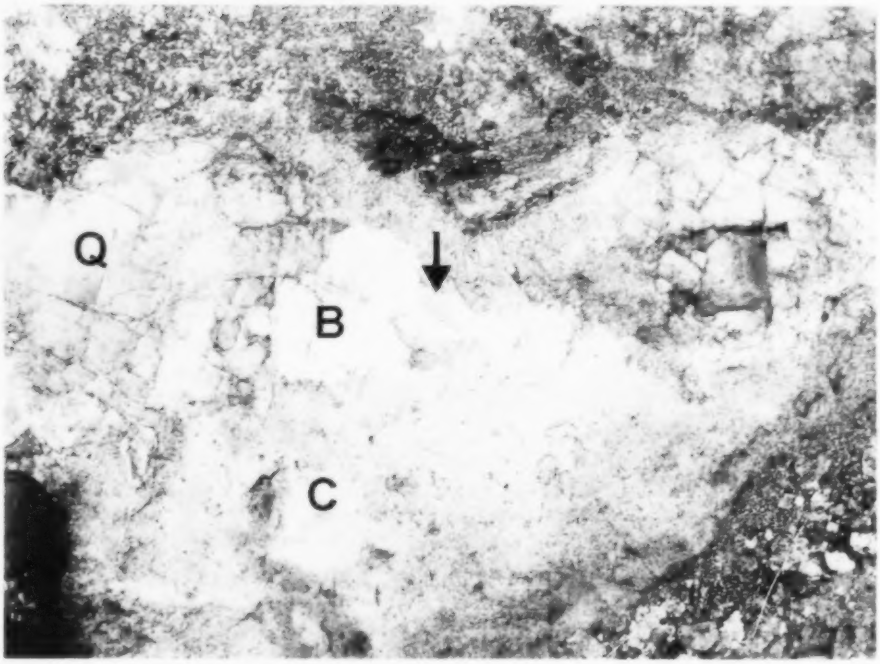


Photo 41. Ragged crystal remnant of colour zoned beryl (B) with surviving crystal face in contact with quartz-rich mass (Q) to left of coin. The beryl-quartz assemblage is entirely enveloped by cleavelandite-rich masses (C). Arrow points to replacement embayment of cleavelandite into beryl.

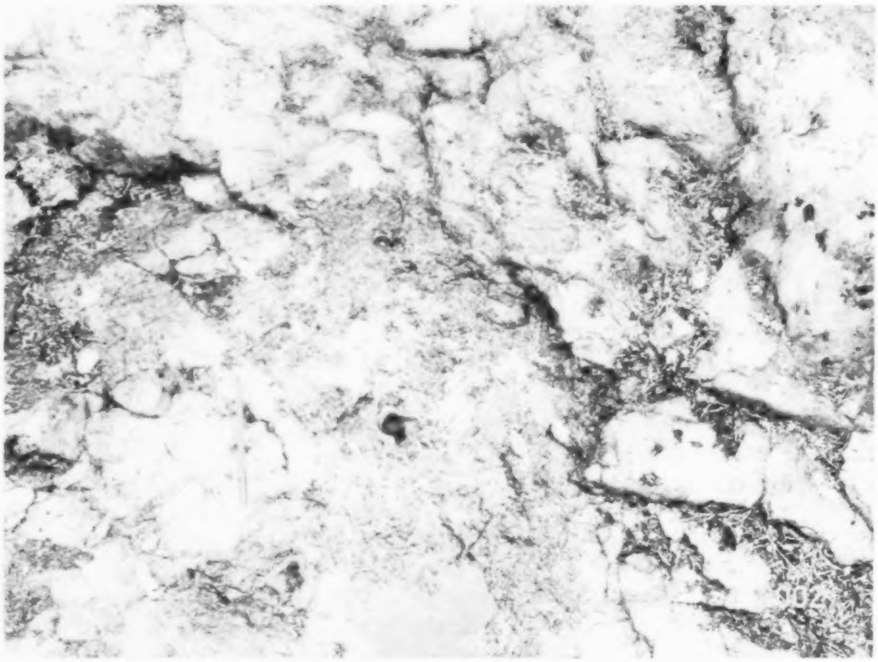


Photo 42. Lepidolite-albite pod completely enveloped by the quartz-rich core zone.

Table 11. Rare-element content and selected element ratios in muscovite bulk compositions in pegmatitic granite and rare-element pegmatite of the Hearst area.

Sample #		Be (ppm)	Cs (ppm)	Li (ppm)	Nb (ppm)	Rb (ppm)	Sn (ppm)	Ta (ppm)	K/Cs	K/Rb	Nb/Ta
Montcalm Creek Quarry (McCrea Township)											
02-JBS-01-02		6.9	91	102	174	1032	66	32	944	83	5.4
02-JBS-02-04		14.4	201	66	319	1225	77	50	443	73	6.4
02-JBS-02-07		8.8	58	82	1080	646	38	49	1510	136	22.0
	Mean	10.0	117	83	524	968	60	44	966	97	11.3
Shetland Township pegmatitic granite											
02-JBS-17-02		5.4	24	292	213	794	123	12	3617	109	17.8
Pagwachuan River pegmatitic granite zone											
02-JBS-10-01		11.3	266	76	394	2252	697	83	322	38	5.4
Lowther Township complex-type, lepidolite-subtype pegmatite system											
Parent pegmatitic granite host											
02-JBS-11-31		16.8	150	2743	460	3064	781	54	586	29.0	8.5
Lowther Township pegmatite											
LT-97MU1		17	264	1360	363	5474	530	71	332	16.0	5.1
LT-97MU2		17	222	2452	422	4633	620	66	388	18.6	6.4
02-JBS-11-14		15.4	210	2343	395	4609	582	58	408	18.6	6.8
02-JBS-11-18		13.1	154	3572	458	3008	835	50	565	28.0	9.2
02-JBS-11-34		15.7	325	2220	367	6661	493	63	265	13.0	5.8
	Mean	15.8	221	2448	411	4575	640	60	424	20.5	7.0

Notes:

02-JBS-01-02: Silver muscovite from coarse-grained, garnet-muscovite-biotite granite
02-JBS-02-02: Silver muscovite from muscovite-biotite potassic pegmatite
02-JBS-02-07: Light green muscovite from coarse-grained, garnet-tourmaline-muscovite leucogranite
02-JBS-17-02: Silver to light brown muscovite from muscovite potassic pegmatite
02-JBS-10-01: Light green muscovite from muscovite potassic pegmatite
02-JBS-11-31: Light green muscovite from parent pegmatitic granite about 50 m south of Lowther Township pegmatite
LT-97MU-1: Silver muscovite from sodic pegmatite wall zone
LT-97MU-2: Silver muscovite from sodic pegmatite wall zone
02-JBS-11-14: Light green muscovite near the quartz core zone
02-JBS-11-18: Light green muscovite near quartz core zone
02-JBS-11-34: Light green muscovite from pit near to coarsest beryl crystal

Petrochemistry of Lowther Township Pegmatite

Eight bulk rock compositions of the various zones of the Lowther Township pegmatite are given in Table 8 (*see* Tindle, Selway and Breaks 2006 (MRD 210)) and the main chemical features are summarized in Table 9.

The parent granite, composed of muscovite-biotite sodic pegmatite, was sampled 10 m from the southern contact of the Lowther Township pegmatite. This rock (02-JBS-11-40: *see* Tindle, Selway and Breaks 2006 (MRD 210), Table 8) contains high SiO_2 (83.06 weight %) and a high Na_2O/K_2O ratio (6.2) that reflects the modal dominance of albite and quartz. Only meager levels of the various rare-elements are obvious in Table 9 as only low modal abundances of biotite, muscovite and potassium feldspar are present, as reflected in K_2O level (0.77 weight %).

The sodic pegmatite wall zone of the Lowther Township pegmatite, however, reveals significant increase in chemical evolution as indicated by the decrease in the K/Rb ratio (18 versus 130 for parent granite) and elevated Li (221 ppm), Rb (286 ppm), Cs (112 ppm) that are probably contained in the zinnwaldite-rich aggregates. Tantalum (8 ppm), Sn (12 ppm) and Nb (39 ppm) are low relative to the innermost zones, owing to a sparsity of tantalum-niobium oxide minerals (*see* Tindle, Selway and Breaks 2006 (MRD 210), various tables with electron microprobe data (folder "Probe Data")).

The cleavelandite-rich zone exhibits the widest range of Na_2O/K_2O (0.4 to 1.7) of any internal unit, due to modally variable amounts of green muscovite, the most important potassium-bearing mineral. K/Rb ratios (12.4 to 24.1) overlap with that of the sodic pegmatite wall zone (*see* Table 9). Significantly higher rare-element concentrations are evident in the cleavelandite zone relative to adjacent units (sodic pegmatite wall zone and cleavelandite-rich zone), particularly for lithium, rubidium, and cesium (*see* Table 9). In fact, the highest tantalum, niobium and tin occur in the cleavelandite-rich zone, a feature that is likely due to the affinity of these metals for sodium-rich bulk compositions in pegmatite magmatic systems (London 2005). A similar relationship also applies to tantalum, niobium and tin that are distributed in local tin-bearing manganocolumbite and cassiterite.

The highest lithium contents of any unit occur in the spodumene zone that contains 4.01 to 4.03 weight % Li_2O due to the abundance of spodumene (*see* Table 9). K/Cs and K/Rb ratios overlap with those of the adjacent cleavelandite-rich zone, suggesting a similar degree of chemical evolution.

The highest level of chemical evolution is attained in the quartz-lepidolite-cleavelandite pod (*see* Table 9). This unit contains the highest Rb_2O (0.67 weight %), MnO (0.87 weight %) and most evolved K/Rb ratio (9.8) of any internal zone due to the high amount of lepidolite (estimated 30 volume %).

Elevated zinc and zircon in bulk compositions from the Lowther pegmatite indicate accessory sphalerite and zircon in the Lowther pegmatite that are common minerals in most LCT–family pegmatites of northern Ontario. These minerals, for example, occur in the complex-type, spodumene-subtype Case pegmatite, northeastern Ontario (Breaks, Selway and Tindle 2001) and in the albite-spodumene-type Gullwing Lake pegmatite, northwestern Ontario (Breaks, Selway and Tindle 2003a).

Mineral Chemistry of Lowther Township Pegmatite

The main chemical attributes of several pegmatite-forming minerals are described below that include potassium feldspar, mica minerals (zinnwaldite, muscovite and lepidolite), beryl, tourmaline, garnet and the Ta-Nb-oxide minerals. A summary of the rare-element content and element ratios for pegmatite evolution indicator minerals muscovite and potassium feldspar is given in Tables 9 and 10.

POTASSIUM FELDSPAR

Bulk compositions of blocky potassium feldspar, summarized in Table 10, are mostly from the parent granite with a single sample from an internal unit of the genetically related rare-element pegmatite (cleavelandite-rich zone: LT-97KF-2). The parent granite has ranges of Rb (971 to 3901 ppm) and Cs (82 to 382 ppm) that are similar to fertile granite plutons elsewhere in the Superior Province (Breaks and Tindle 2002). The rubidium and cesium content of potassium feldspar from the cleavelandite-rich zone falls overlaps with that of the parent granite. Electron microprobe compositions, however, reveal higher amounts of Rb_2O (0.40 to 0.69 weight %) and Cs_2O (0.09 to 0.17 weight %).

MUSCOVITE, LEPIDOLITE, AND ZINNWALDITE

These mica minerals reveal compositional variation within the internal units inwards from the parent granite contact:

- sodic pegmatite wall zone: lithian muscovite-zinnwaldite → iron-, manganese- and cesium-rich zinnwaldite
- aplite and cleavelandite-rich zones: tin-bearing, iron-rich muscovite

- lepidolite-cleavelandite pod: manganese-, rubidium-, lithium- and fluorine-rich lepidolite
- quartz-rich core zone: fluorine-rich muscovite

Six bulk compositions of coarse muscovite books from the Lowther Township pegmatite and its parent granite are summarized and compared to other fertile granite-pegmatite systems in the area (*see* Table 11). Similar to the potassium feldspar compositions, muscovite from the parent granite falls within the range of the various rare-elements from the genetically associated Lowther Township pegmatite.

Muscovite compositions, as determined by electron microprobe, reveal similar and locally higher levels of Rb_2O, Cs_2O and Sn_2O. The muscovite in the aplite zone contains moderate rubidium and tin contents: Rb_2O (0.12 to 0.22 weight %), Cs_2O (up to 0.02 weight %) and SnO_2 (0.17 to 0.22 weight %). Manganese-bearing muscovite from the cleavelandite-rich zone contains Rb_2O (0.08 to 0.77 weight %), Cs_2O (up to 0.24 weight %), MnO (0.13 to 0.56 weight %) and up to 0.05 weight % SnO_2. A yellow-green, coarse-grained, 6 cm diameter muscovite crystal near the quartz core contains F (1.41 to 1.77 weight %), MnO (0.20 to 0.29 weight %), Rb_2O (0.31 to 0.41 weight %), Cs_2O (up to 0.03 weight %) and SnO_2 (up to 0.07 weight %). Green muscovite interstitial to cleavelandite blades (02-JBS-11-20) exhibits elevated SnO_2 (0.69 to 0.81 weight %) that is the highest within any internal zone.

A study of muscovite compositions in rare-element pegmatites by Smeds (1992) concluded that there is a strong correlation between high amounts of tin (>500 to 600 ppm Sn) in white, yellow or green muscovite with low magnesium, and the appearance of cassiterite in pegmatites. Data from the Lowther Township pegmatite supports this observation as both cassiterite and tin-rich manganocolumbite have been identified.

Zinnwaldite from the sodic pegmatite wall zone (02-JBS-11-29) contains 1.7 and 2.6 weight % F and a calculated Li_2O content of 2.28 to 2.91 weight %. Electron microprobe compositions Rb_2O (0.26 to 0.71 weight %) and Cs_2O (0.09 to 1.22 weight %). A transitional composition between lithian muscovite and zinnwaldite at 02-JBS-11-16 has a calculated Li_2O content between 3.09 and 3.53 weight %.

The most manganese-rich mica in the pegmatite is the purple lepidolite in the quartz-lepidolite-cleavelandite pod. The lepidolite is fluorine-rich (3.08 to 7.29 weight %) and MnO-rich (1.19 to 2.99 weight %) with elevated Rb_2O (0.77 to 1.18 weight %) and Cs_2O (0.09 to 0.38 weight %) and up to 0.02 weight % SnO_2. The lepidolite contains patches of muscovite with MnO (0.32 to 0.56 weight %), Rb_2O (0.47 to 0.50 weight %), up to 0.05 weight % Cs_2O and no detectable tin.

In the cesium versus tantalum diagram (*see* Figure 28), muscovite bulk compositions from the Lowther Township pegmatite fall between the fields for beryl-type and complex-type pegmatites as exemplified by the Separation Rapids pegmatite group (Breaks and Tindle 2002). This would appear to indicate that although Nb-Ta oxides are present, the potential for high tantalum-bearing minerals (e.g., manganotantalite and wodginite) is likely to be subordinate to ferrocolumbite and manganocolumbite, an inference supported by data in the columbite-tantalite quadrilateral plot (*see* Figure 29).

BERYL

Bulk and electron microprobe composition data reveal significant levels of Cs_2O in beryl. A bulk sample of an entire colour zoned, coarse beryl (similar to Photo 41) contained Cs_2O = 2.6 weight %. Microprobe data from a 9 cm diameter beryl crystal adjacent to the quartz-rich core zone reveals a Cs_2O-rich pink core (2.11 to 2.57 weight %) and a green rim with lower Cs_2O (1.18 to 1.50 weight %) and Na_2O (1.49 to 1.72 weight %) contents. However, similar elevated Cs_2O contents occur in beryl from other highly evolved pegmatites and, for example, overlap the range of the Tanco pegmatite (Černý et al. 1981: 2.47 to 3.27 weight %).

TOURMALINE

The highly evolved nature of the parent granite is further indicated by "fluor-elbaite" tourmaline compositions that were documented in a zoned grain (02-JBS-11-30) with a calcium-bearing schorl-elbaite core and a calcium-bearing "fluor-elbaite"-schorl rim. The presence of spessartine and "fluor-elbaite" in the parent granite indicates the most mineralogically evolved peraluminous granitic rocks of the Hearst area.

Within the Lowther Township pegmatite, tourmaline evolves in composition in the following sequence: calcium-bearing schorl → calcium-bearing schorl-elbaite → calcium-bearing "fluor-elbaite"-schorl → "fluor-schorl"-elbaite. This pattern of compositional change from iron-rich to lithium- and fluorine-rich to iron- and fluorine-rich is also reflected by similar chemical evolution in the mica minerals.

Most of the tourmaline in the sodic pegmatite wall zone is calcium-bearing schorl and calcium-rich schorl, calcium-rich schorl-elbaite, but one sample of tourmaline intergrown with potassium feldspar contains calcium-rich elbaite-schorl with elevated fluorine contents.

Black tourmaline inclusions occur in coarse-grained green muscovite of the cleavelandite-rich zone adjacent to the quartz core and are mostly "fluor-elbaite"-schorl with minor calcium-bearing "fluor-elbaite"-schorl. One grain has a "fluor-elbaite"-schorl (lithium-rich) core and a "fluor-schorl"-elbaite (iron-rich) rim.

GARNET

The garnet compositions exhibit increasing evolution from the parent granite into the various internal units of the Lowther Township pegmatite, as expressed by increasing spessartine and decreasing almandine components. Garnet in the parent pegmatitic granite occurs as inclusions in coarse-grained muscovite and consists of iron-rich spessartine-almandine (57 to 61% spessartine, 38 to 41% almandine). In the sodic pegmatite wall zone, garnet has a similar compositional range and is mainly spessartine-almandine (47 to 62% spessartine, 28 to 50% almandine). In the zinnwaldite-rich pods, however, there is relative enrichment of the spessartine component as determined in zoned garnet inclusions that have spessartine-almandine cores (49 to 55% spessartine, 42 to 48% almandine) and more calcium-rich and iron-depleted, spessartine rims (79 to 82% spessartine, 12 to 16% almandine, 5.5% grossular).

The orange, manganese-rich spessartine-rich garnets, which are particularly abundant within the cleavelandite-rich zone adjacent to the quartz-rich core zone, reveal their highest degree of evolution as indicated by zoned grains that have manganese-rich cores (90% spessartine) and rims. There is also a notable increase in calcium content in the garnet rims (73 to 75% spessartine, 13 to 15% almandine, 9 to 10% grossular).

TANTALUM, TIN AND NIOBIUM OXIDE MINERALS

The Ta-Nb-oxide minerals (*see* Figure 29) increase in tantalum and manganese content in the following evolutionary sequence: ferrocolumbite → manganocolumbite → manganotantalite.

The Ta-Nb oxides in the sodic pegmatite wall zone and the aplite zone with miarolitic cavities range from ferrocolumbite to manganocolumbite and span a similar range of compositions. Tin-rich ferrocolumbite, with elevated SnO_2 (0.78 to 1.17 weight %), was encountered in the wall zone. The Ta_2O_5 content (mean = 7.30 weight %) coupled with a limited Mn/(Mn+Fe) of 0.40 results in an isolated cluster data points in Figure 29. More evolved compositions in the wall zone were found as manganocolumbite inclusions in red-orange spessartine at 02-JBS-11-16 that contain up to 16.32 weight % Ta_2O_5.

The Ta-Nb oxide minerals in the aplite zone consist of tin-bearing, tantalian rutile [(Ti, Ta, Fe) O_2], which contains Ta_2O_5 (10.5 to 11.9 weight %) and SnO_2 (1.22 to 2.16 weight %), and exsolved blebs of ferrocolumbite and manganocolumbite (Ta_2O_5 = 9.68 to 12.24 weight %, SnO_2 = 0.28 to 0.77 weight %). Inclusions of tantalum-bearing cassiterite were also found in the tantalian rutile.

The cleavelandite-rich zone contains generally more evolved manganocolumbite compositions than the adjacent aplite and sodic pegmatite zones. Most of the data points in the columbite group quadrilateral diagram (*see* Figure 29) form a tight cluster that reflect higher manganese with the average Mn/(Mn+Fe) = 0.89 and tantalum contents (range of Ta_2O_5 = 11.92 to 39.45 weight %). Microlite occurs as patch-like domains within manganocolumbite and is interpreted to have developed during late albitization of the pegmatite.

However, the gradational contact between the aplite zone and the spodumene zone contains even more evolved manganocolumbite as indicated by the highest Mn/(Mn+Fe) ratios (mean = 0.99) in the pegmatite and Ta_2O_5 contents (31.5 to 39.8 weight %).

The most evolved Nb-Ta oxide minerals in Lowther Township pegmatite are situated along the contact between the quartz core and cleavelandite-rich zone. Manganocolumbite inclusions with manganotantalite patches were encountered within white, blocky potassium feldspar adjacent to the quartz core. Such oxide grains in this habitat are typically produced by albitization as noted elsewhere by the authors in various rare-element pegmatites of northwest Ontario. The oxide minerals have a mean Mn/(Mn+Fe) = 0.94 with the widest range of Ta_2O_5 in the entire pegmatite (32.03 to 53.66 weight %: *see* Figure 29).

Petrogenesis of Lowther Township Pegmatite

The Lowther Township rare-element pegmatite occurs within the transition between medium- and high-grade metasedimentary rocks that were initially migmatized at 2670±2 Ma (Percival and Sullivan 1988). The parent granite and its related rare-element pegmatite is undeformed and unrecrystallized, which coupled with its 2627±12 Ma age, indicates that its emplacement outlasted the main regional metamorphism responsible for the initial generation of S-type peraluminous granitic rocks in higher grade parts of the metasedimentary-rich Quetico Subprovince. A similar bimodal age distribution of peraluminous magmatism is also found in the Separation Rapids pegmatite group (Breaks and Tindle 2002). There, the initial appearance of S-type, peraluminous pegmatitic granites in the English River Subprovince occurred at 2691±2 Ma (Corfu, Stott and Breaks 1995), whereas emplacement of the highly evolved peraluminous granitic rocks in Separation Rapids pluton developed significantly later at 2646±2Ma (Larbi et al. 1999).

The Lowther Township pegmatite possibly constitutes part of a regionally zoned rare-element pegmatite sequence that increased in evolution from east (Shetland Township beryl-type pegmatite and associated S-type, peraluminous pegmatitic granite) to west (Lowther Township complex-type pegmatite) over a minimum distance of 10 km. Garnet and muscovite compositions from the Shetland Township rare-element occurrence (locality 02-JBS-16) overlap with those of the Lowther Township pegmatite and support a genetic linkage.

Lepidolite-subtype pegmatites are also characterized by high bulk content of fluorine and low phosphorus (Černý 1989), chemical features that are obvious from the mineralogy in which fluorine-bearing phases such as muscovite, "fluor-elbaite", zinnwaldite and lepidolite occur in the complete absence of phosphate minerals.

The Lowther pegmatite crystallized from an *in situ* separation of a water-saturated, pegmatite-forming melt that contained appreciable levels of fluorine and meager boron and phosphorus, as inferred by the mineralogy and bulk chemistry. Water saturation is supported by the following observations:

- coarse muscovite books and zinnwaldite in the sodic pegmatite wall zone
- gradational contact between sodic pegmatite wall zone and the sodium-rich parent granite mass
- miarolitic cavities in some internal pegmatite units (spodumene zone and cleavelandite zone)

Several significant mineral composition trends are notable with increasing evolution of the pegmatite-forming melt, that is, from the wall zone to innermost units:

1. Garnet compositions change from intermediate almandine-spessartine → intermediate spessartine-almandine in the parent granite and sodic wall zone → manganese-rich spessartine in the quartz core.
2. Ta-Nb-oxide minerals reveal a significant increase in manganese and a slight late-stage increase in iron in the quartz core that is similar to that revealed by the garnet compositions.
3. Mica minerals change from lithian muscovite-zinnwaldite → iron-, manganese- and cesium-rich zinnwaldite (sodic pegmatite wall zone) → tin-bearing, iron-rich muscovite (aplite and cleavelandite-rich zones) → manganese-, rubidium-, lithium- and fluorine-rich lepidolite (quartz-lepidolite-cleavelandite pod) → fluorine-rich muscovite (quartz-rich core). Lepidolite from the lepidolite-cleavelandite-rich pods, entirely enveloped by the quartz-rich core zone, contains the highest fluorine contents of any mineral in the entire pegmatite (mean = 4.6 weight %).
4. Tourmaline changes from calcium-bearing schorl → calcium-bearing schorl-elbaite → calcium-bearing "fluor-elbaite"-schorl → "fluor-schorl"-elbaite. The mica and tourmaline composition evolves from iron-rich to lithium- and fluorine-rich to iron- and fluorine-rich.

EXPLORATION RECOMMENDATIONS

The area merits careful prospecting for further rare-element mineralization such as the Lowther Township complex-type pegmatite. Exploration is highly recommended in Shetland Township where a beryl-type, sodic pegmatite dike was discovered with significantly anomalous bulk rock tantalum levels of 78 ppm Ta relative to the average upper continental crust (Taylor and McLennan 1985, p.46), coupled with a highly evolved Nb/Ta ratio of 0.77. This tantalum content represents the highest bulk rock value encountered during the present project. The sodic pegmatite dike could represent part of a swarm of pegmatites that was generated from a nearby small mass of peraluminous pegmatitic granite.

Poor bedrock exposure will render success difficult and, hence, prospectors should consider the following:

- pegmatitic granite masses are erosionally resistant relative to their metasedimentary host rocks and commonly stand out as low rounded hills. This is evident for the parent pegmatitic granite that hosts the Lowther pegmatite, which is marked by a 200 by 250 m topographic high with about 30 m of local relief. The 1:50 000-scale topographic map of Lowther Township and adjacent townships reveal numerous ovoid topographic highs that could represent other, currently undocumented fertile, pegmatitic granite masses with internal rare-element pegmatites.
- recognition of boulders composed of mineralogically evolved pegmatitic granite (i.e., containing muscovite, tourmaline, beryl or orange, manganese-rich garnet) and/or pegmatite-related metasomatic minerals (holmquistite, biotite, tourmaline)

Quetico–Wabigoon Subprovincial Boundary Zone

This area of the Quetico Subprovince, which is accessed by Highway 11 and ancillary logging roads, was examined mainly in the vicinity of the Pagwachuan River system (*see* Figure 26, back pocket) between McCoig Township and the area west of Clavet Township.

PAGWACHUAN RIVER PERALUMINOUS PEGMATITIC GRANITES

No published reconnaissance or detailed geological mapping has been undertaken in this area. The work of Amukun (1983) provides detailed mapping immediately to the west of area examined in this study. The geology along Highway 11, within 27 km of the Quetico–Wabigoon subprovincial boundary zone, largely comprises high-grade, layered metasedimentary migmatite intruded by various types of granitic rocks:

- tonalite-trondhjemite plutons (grey to pale pink, coarse grained, biotite-bearing) that contain gradational pegmatitic masses and are intruded by fine-grained, biotite granite dikes. These rocks are locally deformed as indicated by foliation and lineation structures.
- potassic pegmatite dikes (biotite and garnet-biotite-bearing) that intrude metawacke and likely postdate the grey trondhjemite rocks
- sodic and potassic pegmatite dikes (10 cm to 1.5 m thick, undeformed and contain muscovite, apatite, garnet and black tourmaline)

Tourmaline is common in granites and potassic pegmatites along Highway 11 from the Quetico–Wabigoon subprovincial boundary zone east to Kohler Township. Biotite granite with impressive biotite blades up to 19 cm long and associated garnet-tourmaline-biotite leucogranite was noted at 02-JBS-111 in the Eastside Lake area (UTM 615020E 5513545N, Zone 16). The biotite leucogranite contains garnet and fine-grained tourmaline stringers, isolated coarse-grained black tourmaline, coarse-grained beige potassium feldspar and minor green apatite. The biotite leucogranite has massive fine-grained tourmaline coating fracture planes.

Pink biotite granite intrudes clastic metasedimentary rocks in the Eastside Lake area at 02-JBS-110 (UTM 616300E 5513430N, Zone 16). The biotite granite contains pink potassium feldspar, green plagioclase, quartz, biotite and minor green apatite, black tourmaline and garnet. Vertical fracture planes within this biotite granite are coated with massive fine-grained black tourmaline and minor apatite and muscovite, a feature similarly found at 02-JBS-111. The tourmaline distributed along these fracture planes possibly relates to magnesium- and boron-rich hydrothermal fluids of uncertain origin. The boron may have ultimately originated from high-grade clastic metasedimentary rocks where it was initially contained in muscovite and biotite. Dehydration of these minerals under anatexis is one mechanism of achieving boron release and was also proposed for the widespread tourmaline that is characteristic of the Dryden pegmatite field (Breaks and Moore 1992).

A small outcrop of pink biotite granite occurs on the South Pagwachuan Road (02-JBS-113: UTM 617083E 5510519N, Zone 16) approximately 250 m west of the Clavet Township boundary. The biotite granite contains graphic pink potassium feldspar, garnet-biotite clots in stringers and tourmaline veinlets. Tourmaline was also found in a 3 cm wide quartz vein that intrudes the biotite granite. This biotite granite resembles the biotite leucogranite with garnet-tourmaline stringers at 02-JBS-111.

Clavet Township Beryl Occurrence

Garnet-biotite potassic pegmatite masses intrude metawacke at 02-FWB-03 (UTM 620082E 5513510N, Zone 16) located on Highway 11 along the western boundary of Clavet Township. The pegmatite grades into quartz-rich patches, up to 5 cm by 1 m, with locally abundant black tourmaline and a single, 1 cm diameter, pale green beryl crystal (Photo 43). The beryl crystal was completely removed for laboratory investigation. The same outcrop reveals important temporal relations whereby a second episode of rare-element-bearing, undeformed, apatite-garnet-muscovite<<black tourmaline potassic pegmatite dikes, crosscut the biotite potassic pegmatite (Photo 44). Tourmaline crystals in the late dikes are typically oriented perpendicular to the contact with the metawacke host rock.

In thin section, the fine-grained metawacke mainly consists of biotite, quartz and plagioclase with minor apatite and pyrite. In contrast, the pegmatite mostly contains coarse-grained microcline and quartz, with accessory coarse-grained, quartz-plagioclase graphic intergrowth, garnet and tourmaline. The microcline is perthitic and is altered to saussurite. The garnet is a coarse-grained garnet (up to 1.5 cm) that contains quartz inclusions and is partially altered to chlorite.

A bulk composition of garnet-biotite potassic pegmatite (02-FWB-03-01: *see* Tindle, Selway and Breaks 2006 (MRD 210), Table 8) in the vicinity of the gradation into the beryl-tourmaline-quartz-rich segregation indicated a primitive degree of evolution relative to the late crosscutting pegmatite veins. This is indicated by high Ba (1697 ppm), total REE (265 ppm), depleted Ta (0.3 ppm) and a high K/Rb ratio (430). Blocky potassium feldspar from nearby boudins of potassic pegmatite exhibits a similar primitive chemistry as indicated by its low Rb (197 ppm) and Cs (12 ppm) coupled with an exceedingly high Ba (4155 ppm) content (02-FWB-03-04: *see* Table 10). In contrast, the crosscutting, apatite-garnet-muscovite<<tourmaline pegmatite dikes have a more evolved bulk rock chemistry (02-FWB-03-03: *see* Tindle, Selway and Breaks 2006 (MRD 210), Table 8) as revealed by its elevated Be (10.6 ppm), Ta (20 ppm), and significantly lower Ba (35 ppm), total REE (11.2 ppm), K/Rb (169) and Nb/Ta (0.8).

The pale green beryl in the quartz-rich patch contains low amounts of Na_2O (0.17 to 0.38 weight %) and Cs_2O (0.07 to 0.13 weight %). The "biotite" is phlogopite-siderophyllite with moderate Rb_2O contents (up to 0.13 weight %) and no detectable cesium.

The garnet, fluorapatite and tourmaline compositions in the late crosscutting pegmatite veins are amongst the most evolved in the Pagwachuan River area. The garnet reveals 2 distinct compositions: orange red unaltered intermediate almandine-spessartine (52 to 54% almandine and 41 to 47% spessartine) and red magnesium- and calcium-bearing almandine (66 to 72% almandine, 10 to 25% spessartine, 4 to 9% grossular) that has partially altered to biotite. The fine-grained blue fluorapatite contains moderate amounts of MnO (0.86 to 2.86 weight %). The tourmaline is zoned with blue, schorl-foitite cores and dark blue, magnesium schorl rims.

Mineral Chemistry of Pagwachuan River Fertile Granites

The fertile peraluminous pegmatitic granites in the Pagwachuan River area can be simplified into 3 main rock types: biotite granite, biotite leucogranite and biotite potassic pegmatite. These rock types may contain accessory garnet and tourmaline. The pegmatitic granites intrude metawacke. The tourmaline potassic pegmatite contains quartz-rich (02-JBS-05, 02-FWB-07 and 02-FWB-08) or beryl-bearing, tourmaline-quartz patches (02-FWB-03). The leucogranite contains tourmaline-garnet stringers at 02-JBS-111 and garnet-biotite stringers at 02-JBS-113. Massive fine-grained black tourmaline coats fracture planes at 02-JBS-110 and 02-JBS-111. The compositions for the garnet, tourmaline and fluorapatite plot as tight clusters for all localities in the Pagwachuan River area and, thus, the descriptions will be grouped

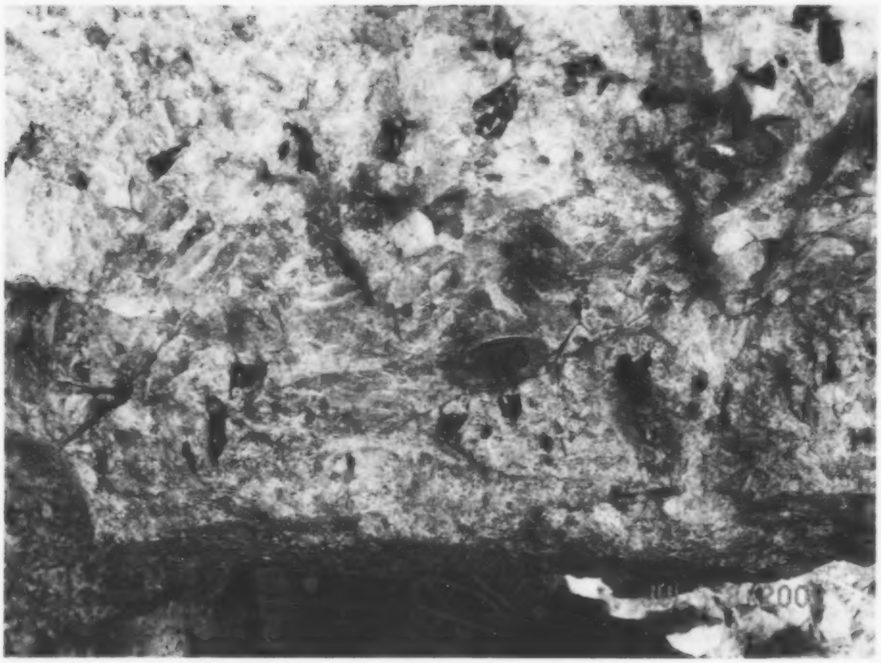


Photo 43. Single green beryl crystal in tourmaline-quartz-rich pod of pegmatitic leucogranite, Clavet Township.

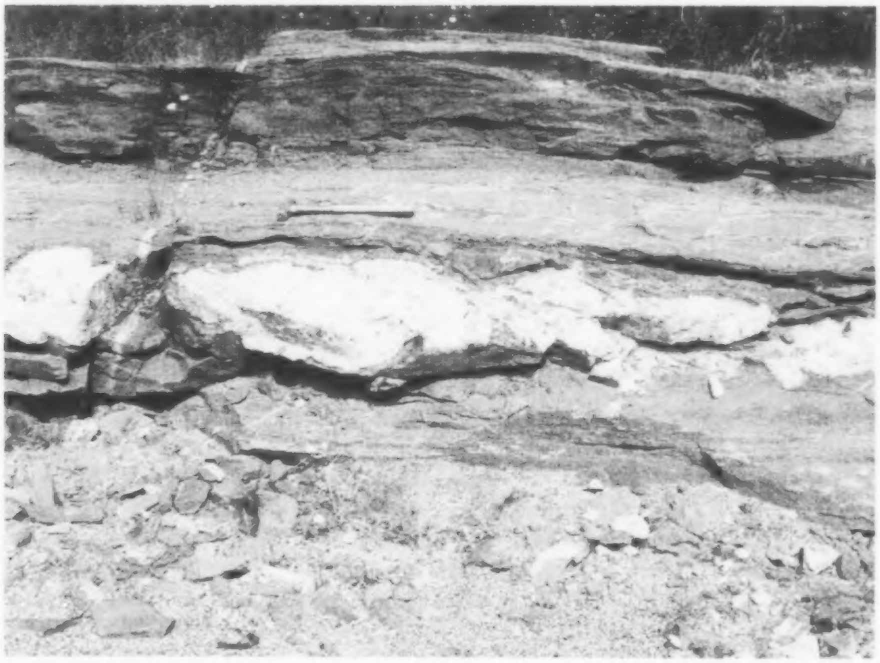


Photo 44. Late, undeformed dike of apatite-garnet-muscovite<<black tourmaline pegmatite that crosscuts boudins of biotite potassic pegmatite, Clavet Township.

together. The beryl occurrence at 02-FWB-03 will be discussed separately as some of its pegmatite units are more fractionated than that at the other localities. The Pagwa quarry locality also will be discussed separately, as it constitutes a sizeable outcrop with considerable petrological variation.

Garnet compositions in pegmatitic granites of the Pagwachuan River area generally comprise magnesium-bearing almandine generally with 11 to 35% spessartine. Garnet with greater than 2% grossular (i.e., calcium) content is generally altered to biotite along fractures and cleavage planes. The most manganese-rich garnets were encountered in late, discordant dikes of apatite-garnet-biotite potassic pegmatite dikes hosted in biotite tonalite at 02-FWB-01. Here, dark orange, intermediate spessartine-almandine contains 46 to 53% spessartine and 39 to 47% almandine.

Tourmaline in thin section can be zoned in thin section from a blue core to an olive green rim in plane polarized light. Electron microprobe data from zoned tourmaline crystals indicate the following crystallization sequence: magnesium-bearing foitite-schorl → magnesium-bearing schorl-foitite → magnesium-rich schorl → schorl-dravite → dravite-schorl. This series indicates a decrease in iron and an increase in magnesium and sodium with crystallization of tourmaline. The iron-dominant tourmaline (and garnet) likely crystallized from a granitic pegmatitic melt that was subsequently contaminated by magnesium due to interaction with the host rocks. The coarse-grained tourmaline (up to 3 cm in diameter) in tourmaline potassic pegmatite with quartz-rich patches tends to be magnesium-bearing foitite-schorl (iron-rich). The late-stage, fine-grained, massive tourmaline-coated fracture planes in biotite granite is typically dravite-schorl (magnesium-rich).

A limited database of 7 potassium feldspar compositions (*see* Tindle, Selway and Breaks 2006 (MRD 210), Table 5) reveals a range of Rb (197 to 1038 ppm) and Cs (9 to 61 ppm) that generally reflect poorly fractionated pegmatitic granites, but more evolved than those from the Hearst–Bannerman area. Rubidium concentrations that are comparable to fertile pegmatitic granite systems elsewhere in Ontario, as in the Separation Rapids pegmatite group (Breaks and Tindle 2002), are summarized in Table 10 and were only encountered in potassium feldspar at 02-FWB-06 and 02-FWB-08 (517 and 1038 ppm Rb, respectively).

Pagwa Quarry

This large quarry, excavated by Villeneuve Construction of Hearst for road-building aggregate, is located just west of the Pagwachuan River bridge on Highway 11 in Clavet Township (UTM 626630E 5513683N, Zone 16). The excellent exposure provides a unique opportunity to examine the three-dimensional aspect of peraluminous granitic pegmatite masses hosted in metawacke (Photo 45a) within a subprovince boundary zone.

The main rock type (western end of quarry) is white, garnet-biotite potassic pegmatite that has fractionated into quartz-rich patches with impressive pink, blocky potassium feldspar, coarse-grained columnar black tourmaline crystals up to 2 cm in diameter and muscovite (Photo 45b). An intermediate zone consists of tourmaline-garnet-biotite potassic pegmatite (02-JBS-09-10). This rock consists of very coarse-grained, pale pink potassium feldspar, quartz, fine-grained red garnet, fine-grained biotite, tourmaline and rare, fine-grained green apatite. The tourmaline occurs in graphic intergrowths with quartz and as columnar black crystals up to 4 cm long. Bulk rock compositions of this intermediate zone indicate elevated Ba, Sr and Zr contents (respectively, 1048 ppm, 174 ppm and 202 ppm).

Blocky potassium feldspar from the quartz-rich patch reveals only modest chemical evolution compared to other pegmatite dikes in the Pagwachuan River area (*see* Tindle, Selway and Breaks 2006 (MRD 210), Table 5) as indicated by the Rb (398 ppm) and Cs (18 ppm) levels. However, a single bulk

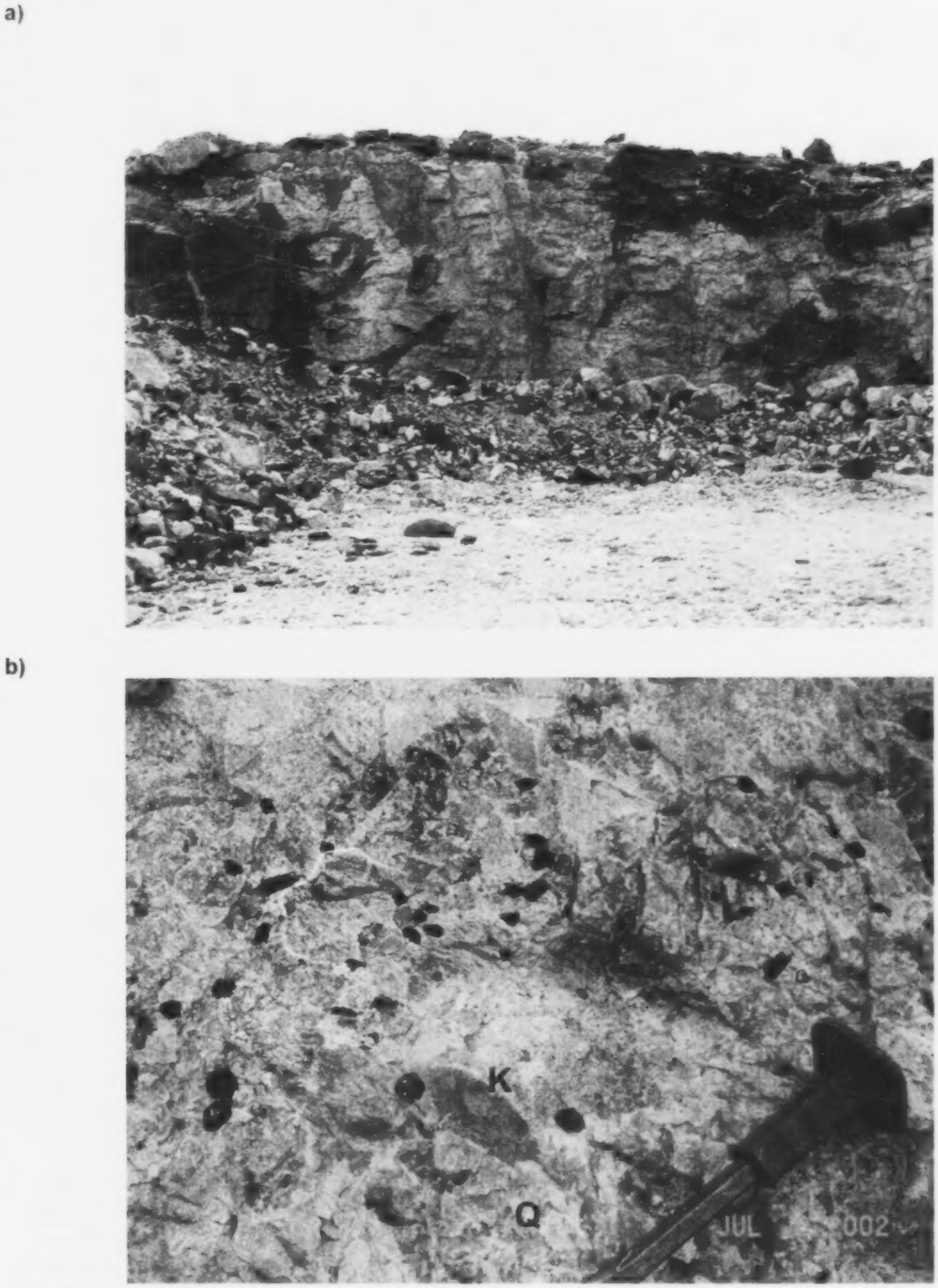


Photo 45. Pagwa quarry. a) Western quarry wall that reveals a vertical section across a white, garnet-biotite potassic pegmatite mass emplaced in metawacke. b) Quartz-rich zone with coarse blocky potassium feldspar (K), robust black tourmaline and muscovite embedded in grey quartz (Q), as revealed on a blast piece at the western end of quarry.

muscovite composition from the muscovite-tourmaline-potassium feldspar-quartz patch (*see* Figure 28) shows that the pegmatite dike system advanced to fertile status, on the basis of anomalous Ta (83 ppm), Rb (2252 ppm), Cs (266 ppm), exceptionally high Sn (697 ppm) and evolved ratios K/Rb (38), K/Cs (322) and Nb/Ta (4.7). The high tin concentration overlaps with the range in muscovite from the Lowther Township pegmatite (493 to 825 ppm: *see* Tindle, Selway and Breaks 2006 (MRD 210), Table 5). It is, therefore, possible that inclusions of cassiterite occur in muscovite from the Pagwa quarry, which is inferred from Smeds (1992), but were not definitively established by the present survey. Inclusions of ferrocolumbite (02-JBS-10-01A) were, however, found in muscovite (Figure 30) and contain the following: Ta_2O_5 (11.9 to 13.3 weight %), Nb_2O_5 (64.7 to 65.0 weight %) and WO_3 (1.3 to 1.9 weight %).

The central part of the quarry wall exposes a vertical, deep pink to red, dike of tourmaline-biotite potassic pegmatite. The red colouration is caused by hematite staining of the abundant potassium feldspar in this dike. The dike also contains dark green, mica-rich aggregates (5 to 10 volume %) that possibly represent altered cordierite. The bulk rock composition of this dike (02-JBS-09-06), compared to other samples from the quarry, reveals low SiO_2 (53.51 weight %) and high CaO (8.44 weight %) and CO_2 (7.21 weight %), the latter 2 values largely due to calcite. Total iron as Fe_2O_3 (2.63 weight %) and Nb (81 ppm) are also elevated relative to the other samples from the quarry.

The eastern end of the quarry wall exposes 3 vertical, white, potassic pegmatite dikes and 1 flat-lying, potassic pegmatite dike (Photo 45c). The vertical dike consists of a 1 m thick wall zone of coarse-grained biotite granite and a main zone composed of garnet-biotite-muscovite potassic pegmatite. Bulk rock composition of the wall zone (02-JBS-09-02) indicates elevated barium and strontium contents (1247 ppm Ba and 222 ppm Sr). The late, 15 to 30 cm wide, discordant dike consists of an aplite border zone and an inner unit of pale pink, tourmaline-biotite potassic pegmatite that contains elevated Rb (353 ppm Rb) and the highest bulk Cs level (15 ppm) of any quarry (02-JBS-09-04: *see* Tindle, Selway and Breaks 2006 (MRD 210), Table 8).

c)

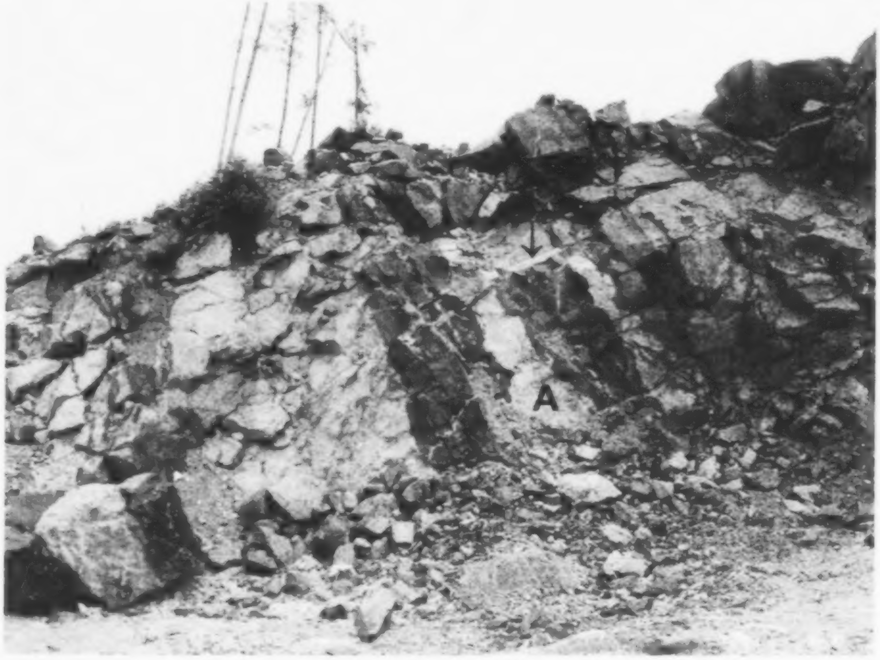


Photo 45, continued. Pagwa quarry. c) Eastern end of the quarry that reveals vertical dikes of partly hematized, biotite potassic pegmatite (A) crosscut by a late, discordant, flat-lying dike of similar composition (arrow).

Red garnet from a garnet-biotite-muscovite potassic pegmatite dike (02-JBS-09-08) consists of magnesium- and calcium-bearing almandine with 10 to 19 weight % spessartine. The garnet is zoned with magnesium-enriched cores and manganese-enriched rims and is partially altered to biotite. The orange-red garnet (02-JBS-09-13) from tourmaline-garnet-biotite potassic pegmatite (intermediate zone in the main body) is magnesium-bearing almandine (with 20 to 21% spessartine).

Tourmaline is schorl-dravite in the white, garnet-biotite-muscovite potassic pegmatite (eastern end of the quarry) and in tourmaline-garnet-biotite potassic pegmatite (western end of the quarry). The pink, vertical dikes of tourmaline-biotite potassic pegmatite (central part of the quarry) contain magnesium-bearing schorl-foitite tourmaline compositions.

Fluorapatite in the white, garnet-biotite-muscovite potassic pegmatite and in the tourmaline-garnet-biotite potassic pegmatite contains moderate amounts of MnO (0.27 to 0.65 weight %).

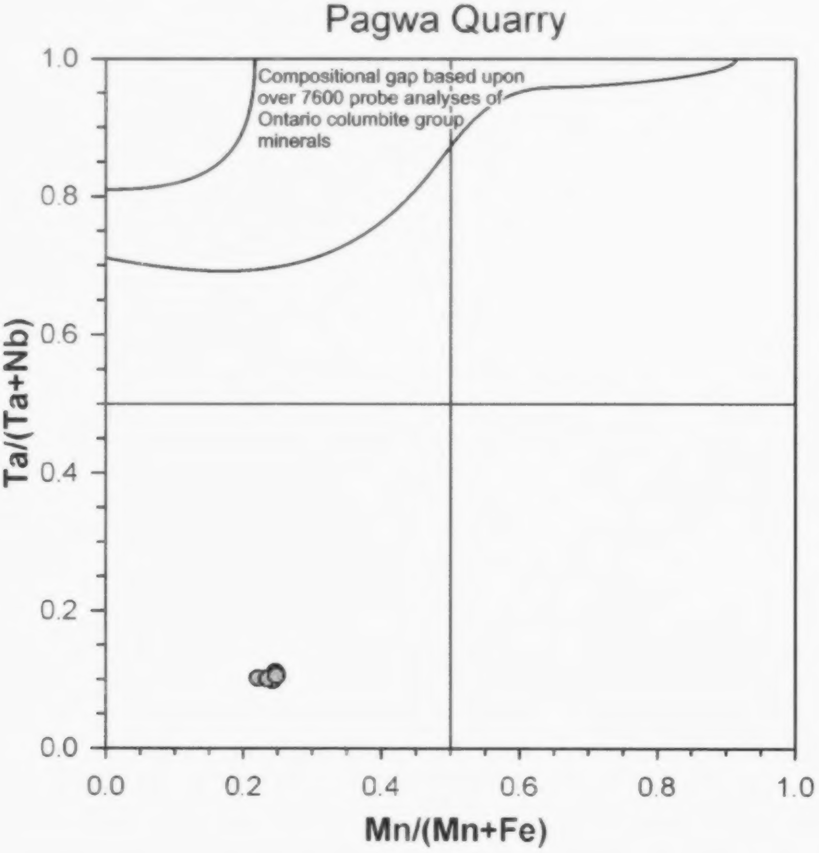


Figure 30. Columbite-tantalite quadrilateral plot (atomic ratios) for pegmatitic granite from the Pagwa quarry. Compositional gap between ferrotapiolite and ferrotantalite is based upon 7600 compositions of columbite-tantalite from Ontario. Microlite compositions may plot within this compositional space.

EXPLORATION RECOMMENDATIONS

The abundance of late, tourmaline-rich pegmatite dikes and an earlier generation of tourmaline associated with biotite and garnet-biotite potassic pegmatite masses, as revealed in the Pagwa quarry, represents a positive feature for rare-element exploration with the Quetico–Wabigoon subprovincial boundary zone. Boron, present in the tourmaline crystal structure, is regarded as an important volatile for complexing of the various rare elements during the genesis and emplacement of granites and related pegmatite dikes (London 1987) that could apply in the Pagwachuan River region.

Of significance for exploration is locality 02-FWB-03 on Highway 11 that reveals 2 episodes of pegmatitic granites that have elevated rare-element contents. The early potassic pegmatite boudins reveal locally advanced fractionation into quartz-rich patches that contain abundant black tourmaline and a single, 1 cm diameter, crystal of pale green beryl. Thus, tourmaline-biotite potassic pegmatites, which otherwise could be superficially deemed as "primitive", were at least locally capable of concentrating beryllium levels required for the precipitation of beryl. London and Evensen (2002) estimated that 95% crystallization of a parental granitic melt, which initially contained 6 ppm Be, is required in order to achieve beryl saturation.

The late, crosscutting, undeformed tourmaline-rich pegmatite dikes contain anomalous tantalum contents and low Nb/Ta and K/Rb ratios that indicate evolved compositions. The Pagwa quarry provides further direct evidence that rare-element concentration processes developed in pegmatitic granites of the area as indicated by ferrocolumbite inclusions and anomalous tin levels in muscovite.

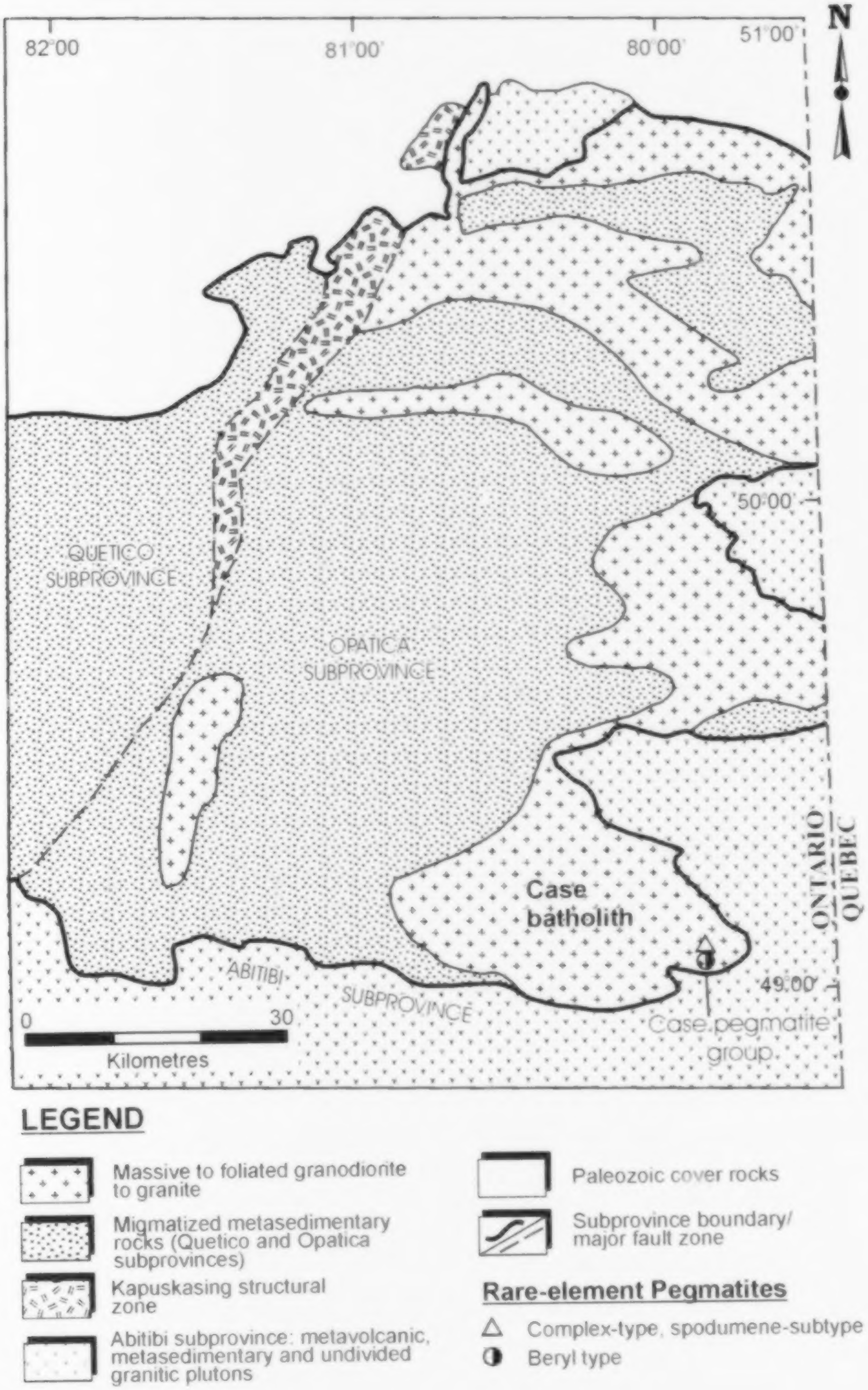
Hence, follow-up prospecting is warranted in the area to look for more evolved tourmaline-bearing pegmatites that could contain lithium- and tantalum-rich minerals. Mineral compositions of garnet, tourmaline, muscovite and potassium feldspar could potentially serve as "pathfinder" minerals in the delineation of potential clusters of evolved, Li-Rb-Cs-Ta-enriched pegmatites.

Opatica Subprovince

Rare-element mineralization in the Opatica Subprovince is currently known only at the Case pegmatite in the Lake Abitibi area (Figure 31). Nevertheless, this spodumene-subtype pegmatite comprises the fifth largest lithium-rich pegmatite in the Superior Province of Ontario.

CASE BATHOLITH

A garnet-biotite-muscovite potassic pegmatite dike (2 m wide) intrudes biotite tonalite within the Case batholith at 02-JBS-120 (UTM 580467E 5438989N, Zone 17) and is situated about 8 km north of the Case pegmatite system. The garnet consists of almandine with elevated manganese contents (31 to 37% spessartine). A muscovite bulk composition has modestly evolved Li (768 ppm), Rb (1026 ppm), Nb (348 ppm) contents, but lower Cs (28 ppm) and Ta (17 ppm). These concentrations are compared to those in bulk muscovite from the least evolved part of the Case pegmatite system, that is, the South Dike beryl-type pegmatite (*see* Tindle, Selway and Breaks 2006 (MRD 210), Table 5).


82°00
81°00'
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50°00'
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QUETICO SUBPROVINCE
OPATICA SUBPROVINCE
ABITIBI SUBPROVINCE
Case batholith
Case pegmatite group
ONTARIO
QUEBEC
0
30
Kilometres
LEGEND
Massive to foliated granodiorite to granite
Migmatized metasedimentary rocks (Quetico and Opatica subprovinces)
Kapuskasing structural zone
Abitibi subprovince: metavolcanic, metasedimentary and undivided granitic plutons
Paleozoic cover rocks
Subprovince boundary/ major fault zone
Rare-element Pegmatites
△ Complex-type, spodumene-subtype
◑ Beryl type

Figure 31. General geology and location of the Case rare-element pegmatite group.

CASE PEGMATITE

This swarm of 3 pegmatites has been an intermittent focus of exploration interest since its discovery in 1959 by Lumbers (1962, p.29). An early investigation generally characterized the mineralogy that documented columbite-tantalite and pollucite, and selected a bulk sample of pollucite-bearing material in which 5.79 weight % Cs_2O was reported (Nickel 1963). Recent work (Horne 2000) involved extensive stripping and Wajax machine washing over most of the exposed strike length of 290 m, followed by channel sampling and total field magnetic and magnetic gradient ground geophysical surveys. Platinova Resources (Platinova Resources, news release, August 8, 2001) subsequently optioned the property in order to assess the tantalum potential of the Case pegmatite system. An average content of 0.024 weight % Ta_2O_5, with a range of 0.003 to 0.068 weight %, was calculated from 16 grab samples selected by Horne (2000). Results from channel sampling and a limited diamond-drill program established an average of 0.024 weight % Ta_2O_5 across 8 m in the Central Dike and a range of 0.011 weight % (over 1 m) to 0.032 weight % Ta_2O_5 (over 7.7 m) for the North Dike (Platinova Resources, news release, October 4, 2001).

The Case pegmatite system is hosted in the southeastern part of the Case batholith, an extensive 50 by 85 km, ovoid granitic complex that is apparently part of the Opatica Subprovince (Jackson and Fyon 1991). The immediate host rocks of the pegmatite dikes consist of massive to subtly foliated, biotite tonalite that is characterized by biotite-rich orbicules that range in diameter from 1 to 7 cm (Photo 46). Such entities are classified as proto-orbicules (Leveson 1966) and commonly exhibit a linear alignment that is parallel to the weak foliation of its tonalite host. The foliation of the biotite in the tonalite is perpendicular to the contact with the pegmatite. The orbicules consist mainly of biotite (90 to 95 volume %), with minor microcline, quartz, and sparse titanite, epidote and apatite.

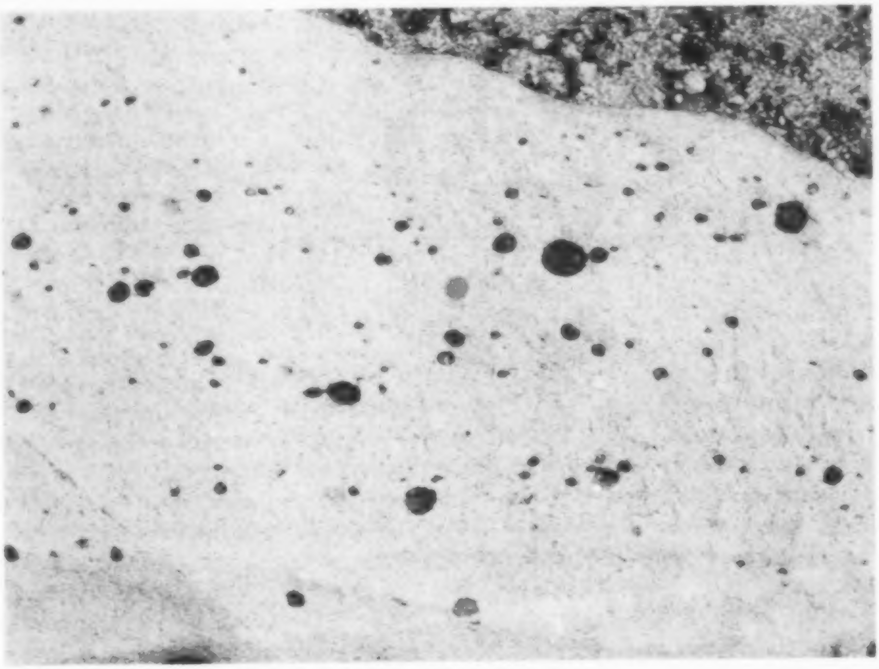

Photo 46. Orbicular tonalite host rocks adjacent to the Case North pegmatite dike.

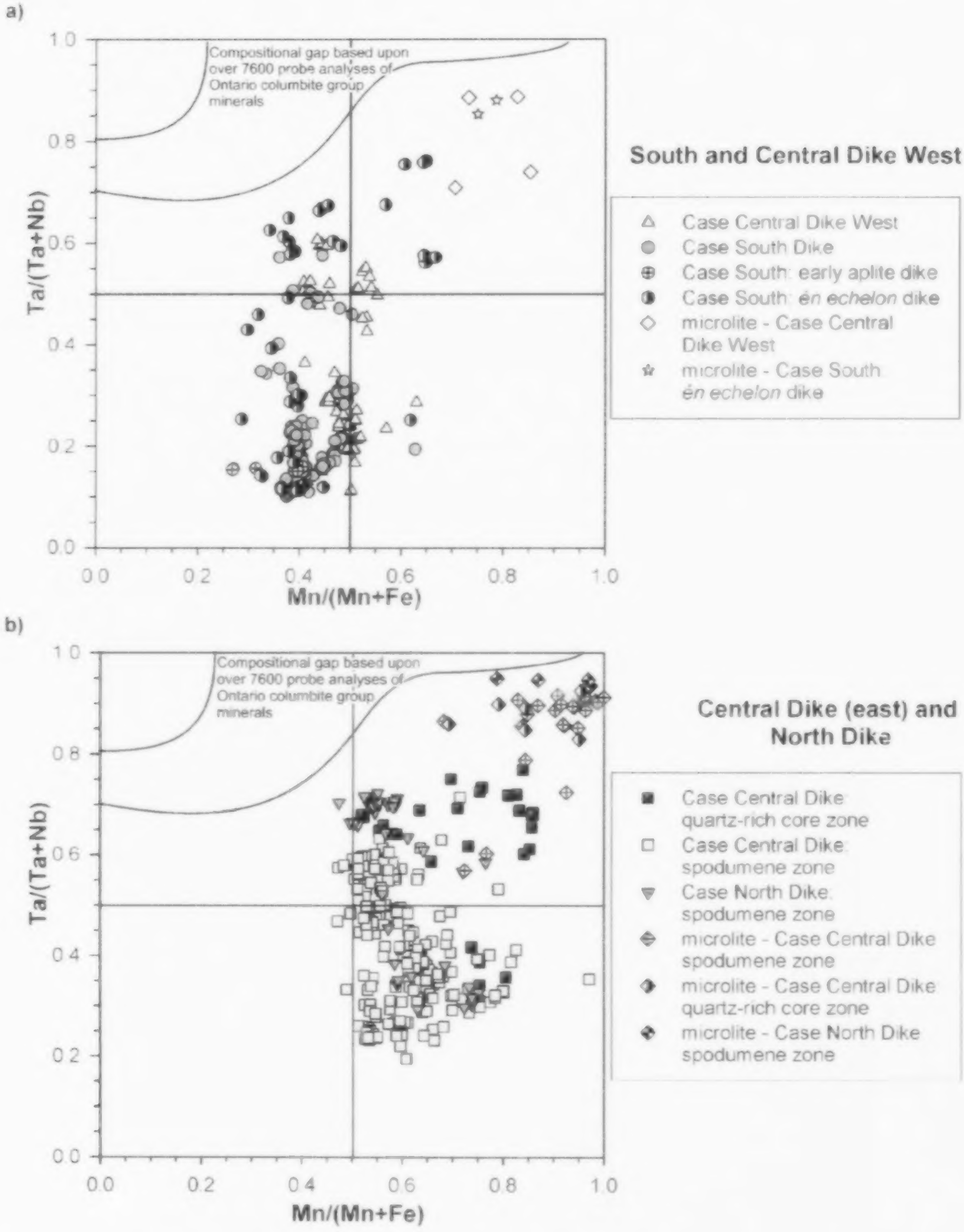

Figure 32. Columbite-tantalite quadrilateral plot (atomic ratios) for the Case complex-type, spodumene-subtype pegmatite: a) South Dike and Central Dike (west part) and b) Central Dike (eastern part) and North Dike. Compositional gap between ferrotapiolite and ferrotantalite is based upon 7600 compositions of columbite-tantalite from Ontario. Microlite compositions may plot within this compositional space.

A metasomatic halo exists in the tonalite up to 10 cm from the contact with the pegmatite. The tonalite close to the contact contains green muscovite likely of exomorphic origin, whereas the unaltered tonalite contains only biotite.

The geology of the Central and North dikes has been previously discussed by Breaks, Selway and Tindle (2001, 2002). A detailed interpretation of the mineral chemistry of these dikes was also undertaken (Breaks, Selway and Tindle 2003a).

The pegmatite swarm, which strikes at 060 to 070° and dips 40 to 60° north, consists of 3 *en échelon* dikes exposed within a 260 by 350 m area situated immediately east of the contact between the Case batholith and Scapa metasedimentary rocks (Lumbers 1962):

South Dike	(10 m thickness and >250 m strike length)
Central Dike	(39 m thickness and >350 m strike length)
North Dike	(12 m thickness and >100 m strike length)

The Central and North Dikes are very similar in mineral assemblage and pegmatite zonation. The most significant difference between the South Dike and the Central and North Dikes is that spodumene is absent in the South Dike, but abundant in the North and Central Dikes. Green beryl is locally abundant in all 3 dikes. Thus, the Case pegmatite system increases in the evolution of its mineral assemblages from the beryl-type South Dike to the complex-type, spodumene-subtype Central and North Dikes.

Early Aplite Dikes

Thin aplite dikes (<10 cm thickness) are exposed on the drill road near the southern contact of the South Dike. These dikes are hosted in biotite tonalite and although crosscut by the South Dike, a genetic association with the nearby South Dike is nevertheless inferred by the presence of minor ferrocolumbite (Figure 32a). These aplites consist mostly of fine-grained granoblastic quartz, plagioclase and microcline, with minor biotite and sporadic chlorite.

Geology of Case South Dike

The South Dike is exposed in 3 outcrop areas as described in detail below.

EASTERNMOST OUTCROP

The easternmost outcrop (UTM 578360E 5431524N, Zone 17) is accessed by a short easterly traverse through the bush from the drill road. The exposure consists of a potassic pegmatite dike that ranges in width from 0.8 to 10 m. An interesting, complex corona texture is evident in the western part of this outcrop area. Here, a large single crystal of potassium feldspar is encased by green muscovite aplite with a minor spessartine-rich garnet layer, which, in turn, is enveloped by an intergrowth of quartz-coarse green muscovite (Photo 47). This type of intergrowth, which contains minor ferrocolumbite, is interstitial to several potassium feldspar-centred corona texture masses and blocky potassium feldspar crystals.

The blocky potassium feldspar crystals are locally slightly albitized along its margins and fractures within the crystal. Ferrocolumbite and spessartine occur in the aplite that invades the blocky potassium feldspar crystals. Green beryl occurs locally in the blocky potassium feldspar zone. The eastern outcrop also contains an albite-muscovite-quartz pod surrounded by a round aplite pod. Euhedral blocky potassium feldspar crystals (up to 54 cm long) occur in a quartz-rich pod (Photo 48).

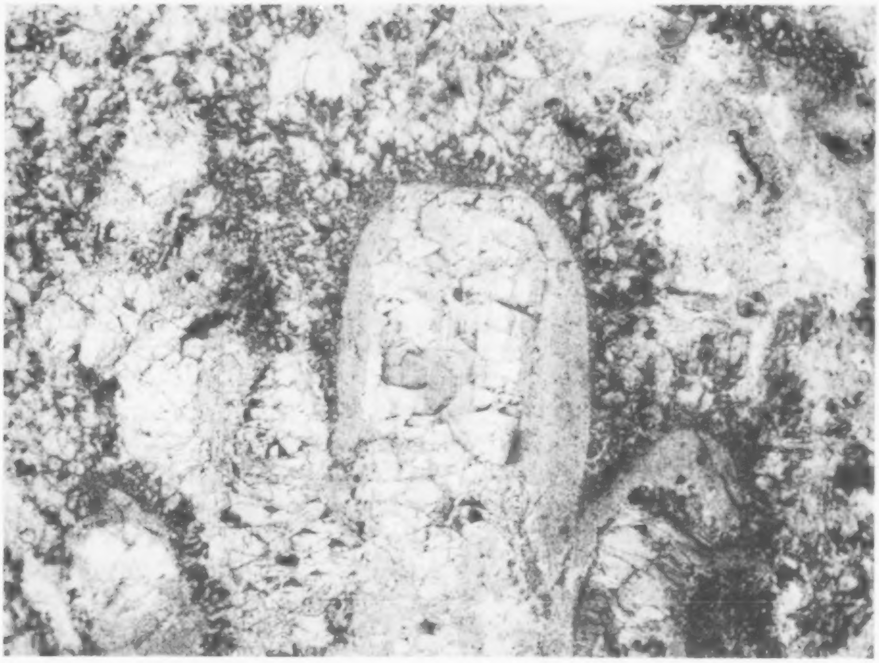

Photo 47. Spectacular corona texture marked by elongate potassium feldspar crystal that served as a substrate for ensuing deposition of muscovite aplite. Eastern outcrop of the Case South Dike.

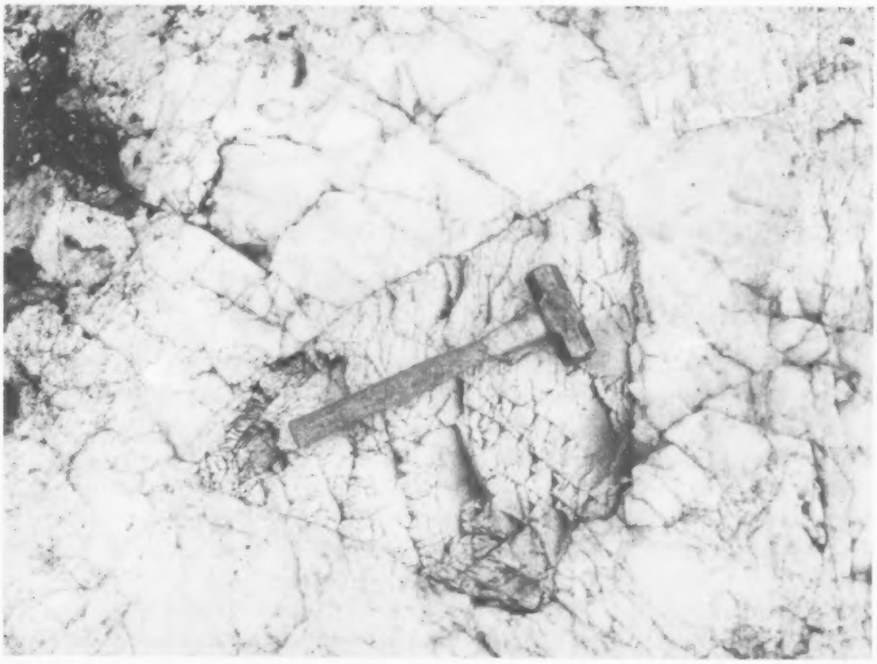

Photo 48. Large blocky potassium feldspar megacryst completely enveloped in a quartz-rich patch, easternmost outcrop of the Case South Dike.

DRILL ROAD OUTCROP

A small outcrop, which occurs along the east side of the drill road (UTM 578365E 5431358N, Zone 17), consists of a potassic pegmatite dike with the following pegmatite zones:

- albite-coarse muscovite-quartz zone (local green beryl and manganese-rich spessartine)
- aplite pods
- blocky potassium feldspar-quartz zone. The blocky potassium feldspar (up to 80 cm long by 36 cm wide) is albitized along its margins and contains ferrocolumbite and ferrotantalite in these replacement patches

MAIN OUTCROP

The main outcrop (UTM 578374E 5431329N, Zone 17) lies to the west of the drill road and differs from the 2 eastern outcrops in a greater abundance of green beryl and garnet aplite. Pegmatitic zoning is also more distinct in the main outcrop area and comprise the following:

- aplite border zone
- quartz-coarse green muscovite zone with minor ferrocolumbite, ferrotantalite, almandine, spessartine, fluorapatite and local green beryl
- albite-coarse muscovite-quartz zone with local abundant fluorapatite (up to 20 volume %) and minor green beryl, ferrocolumbite, manganotantalite and almandine, spessartine
- layered aplite with green muscovite and/or garnet (spessartine and almandine) and minor ferrocolumbite and fluorapatite
- potassium feldspar-green muscovite-quartz zone with minor green beryl
- albitized blocky potassium feldspar-quartz-green beryl

An auxiliary *en échelon* dike (1 m thick) consists of albitized coarse-grained, white potassium feldspar, green muscovite and quartz with minor radiating clusters of platy oxide minerals (ferrocolumbite and microlite) and zoned garnet with spessartine cores and almandine rims.

Geology of Case Central Dike

The Central Dike progressively widens from 10 to 39 m in a west to east direction and, thus, remains open to the east beyond the limits of visible outcrop. The main exposure (Photo 49), within the eastern part of the dike (UTM 578247E 5431660N; Zone 17), reveals a subtly zoned pegmatite that consists of the following units:

- sodic aplite border zone
- quartz-green muscovite zone
- granitic zone and layers (quartz-green muscovite-potassium feldspar)
- garnet aplite pod
- spodumene-rich zone (muscovite-potassium feldspar-quartz-green spodumene-albite)
- quartz-rich core zone
- spessartine-albite<<green muscovite patches
- late dikes of spodumene pegmatite

Photo 49. View of the main exposure of the Case Central Dike looking north towards the North Dike.

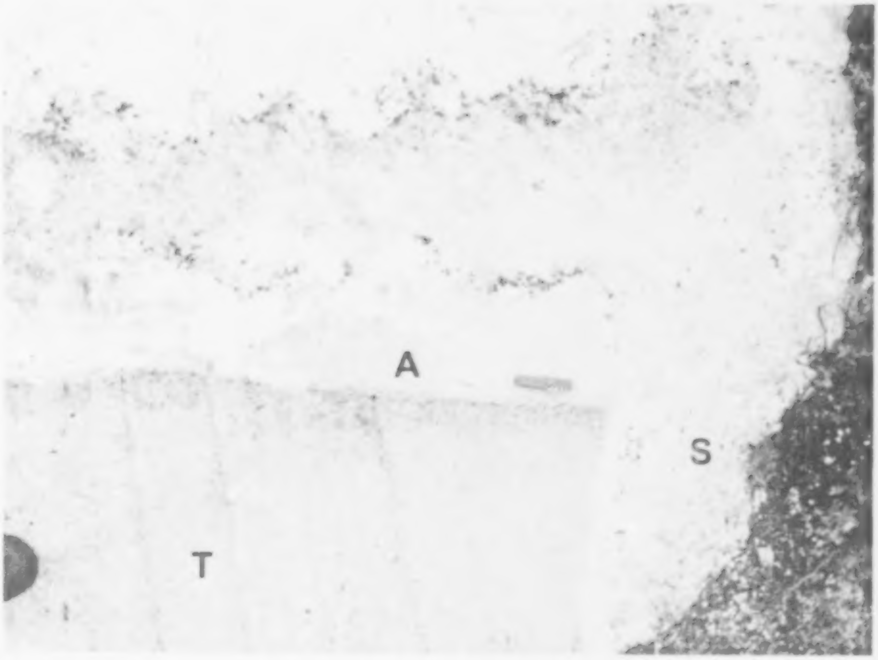

Photo 50. Sodic aplite border zone (A) along the north contact of the Case Central Dike with biotite tonalite (T) host rocks. Note the late intrusion of spodumene pegmatite (S) that crosscuts the aplite layer.

Photo 49. View of the main exposure of the Case Central Dike looking north towards the North Dike.

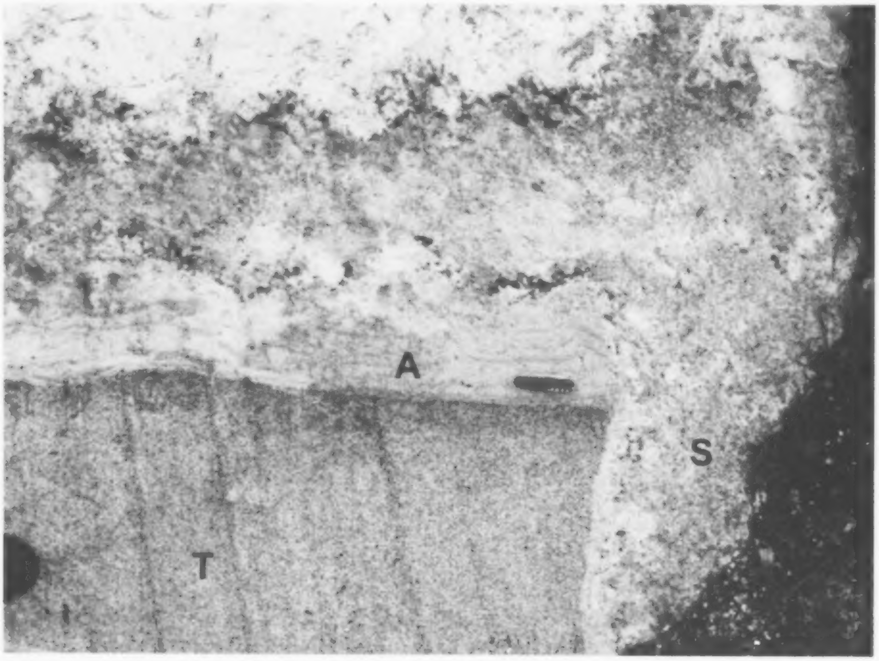

Photo 50. Sodic aplite border zone (A) along the north contact of the Case Central Dike with biotite tonalite (T) host rocks. Note the late intrusion of spodumene pegmatite (S) that crosscuts the aplite layer.

The **sodic aplite border zone** (Photo 50), 5 to 20 cm thick, occurs along both the north and south contacts as a sugar texture, fine-grained, white to pale pink friable rock. The aplite contains garnet stringers and along the northern contact and is intercalated with muscovite-rich and muscovite-poor layers. The aplite also contains granitic layers composed of quartz, muscovite and potassium feldspar. Local green to white beryl tends to occur along the contact between the aplite and the quartz-muscovite-potassium feldspar zone. Minor phases include red spessartine and blue fluorapatite.

The **spodumene-rich zone** (Photo 51) contains abundant very coarse-grained green and white spodumene, white, blocky potassium feldspar, albite and quartz. Minor minerals include muscovite, beryl, platy to radiating clusters of Ta-Nb oxide minerals (manganocolumbite to manganotantalite and microlite) and spessartine. Brown zircon is sparse and very inconspicuous.

The average grain size of the spodumene-rich zone increases from medium grained to very coarse grained as it grades into the quartz-rich core zone. Towards the centre of the dike, a spodumene-rich zone assumes dominance that subsequently grades into a 5 to 10 m by 90 m quartz-rich core zone. The spodumene zone contains coarse-grained, zoned, highly evolved, white to blue (Cs, Na)-rich beryl (*see* "Mineral Chemistry of the Case Pegmatite Dikes").

The **quartz-rich core zone** comprises massive, white quartz (70 to 80 volume %), and the coarsest blocky potassium feldspar (82 by 95 cm) and spodumene megacrysts (5 by 70 cm) found in the entire pegmatite system. Minor phases include green beryl (up to 6 cm across), spessartine, manganocolumbite and manganotantalite.

The **spessartine-albite-green muscovite-rich patches** (Photo 52) are blob-like masses up to 50 by 100 cm, rich in lime green muscovite (80 volume %) and augmented by striking, orange manganese-rich spessartine, albite and spodumene, that occur sparsely in the core zone. The spodumene crystals range in size from 5 by 8 cm to 60 cm by 1.3 m. Rust-stained cavities spodumene megacrysts within and proximal to these muscovite-rich domains and are due to inclusions of weathered sphalerite.

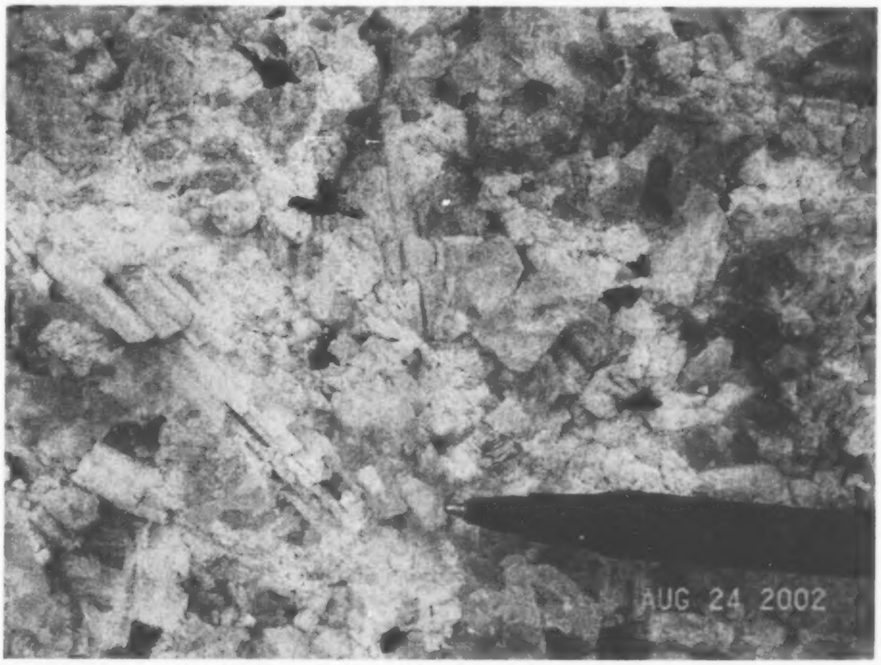

Photo 51. Relatively abundant grains of manganocolumbite-manganotantalite in the spodumene-rich zone of the Central Dike.

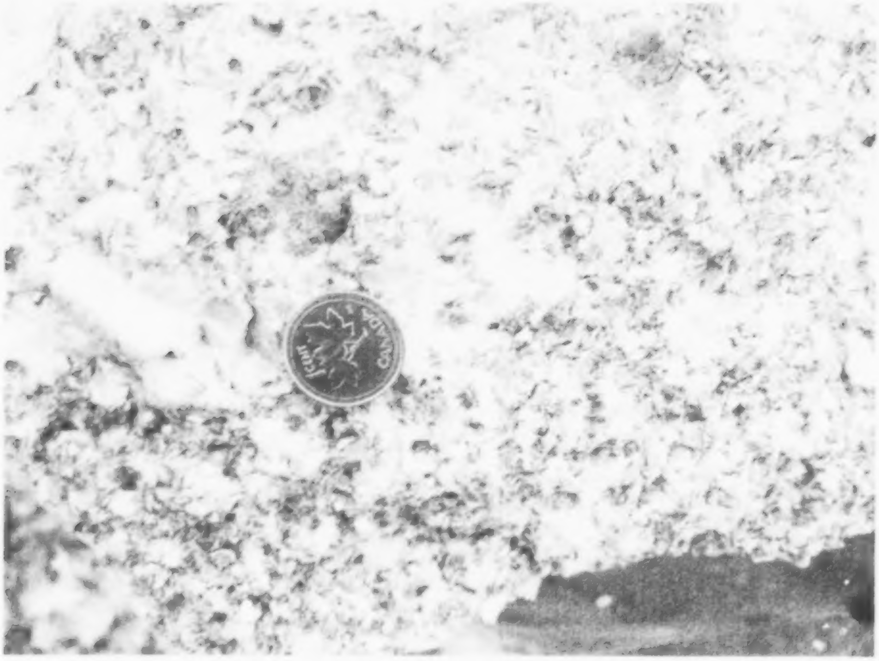

Photo 52. Deep orange spessartine-albite-green muscovite patch, Case Central Dike.

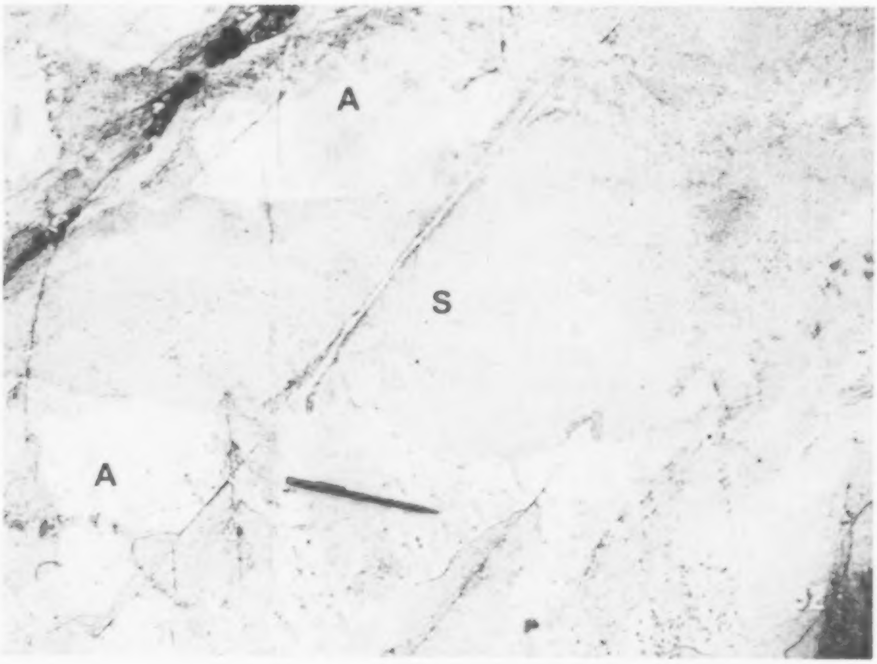

Photo 53. Spodumene granite (S) layered with sodic aplite (A) in the western part of the Case Central Dike.

Late dikes of spodumene pegmatite transect the aplite border zone and progress into the tonalite host rocks, indicating a relatively early solidification for the aplite (*see* Photo 50).

The **western part of the Central Dike** (UTM 578055E 5431567N, Zone 17) exhibits a marked increase in the sodic aplite unit that is typically layered with medium-grained, spodumene granite (Photo 53) and distinctive quartz-ballpeen-texture, dark mica-albite pods. The dark mica is a cesium-bearing muscovite (877 to 1697 ppm Cs) and it occurs with minor fluorapatite and spessartine.

The aplite border zone in the western part contains accessory spessartine, ferrocolumbite, manganocolumbite and fluorapatite. The garnet aplite pods contain minor spessartine and fluorapatite. The spodumene granite, contains fine- to medium-grained green spodumene (20 to 30 volume %), quartz, feldspar, minor muscovite, ferrocolumbite, manganocolumbite, microlite and manganese-rich spessartine, and local green beryl (up to 5 cm).

Geology of Case North Dike

The North Dike (UTM 578131E 5431641N, Zone 17) lies about 10 m north of the Central Dike. It is characterized by layering parallel to its strike (Photo 54) and consists of the following pegmatite zones:

- garnet aplite border zone
- granitic zone (quartz-muscovite-potassium feldspar with minor spessartine)
- aplite pods with minor manganese-rich spessartine
- quartz-rich core zone with euhedral white potassium feldspar
- spodumene-rich zone (muscovite-potassium feldspar-quartz-spodumene)

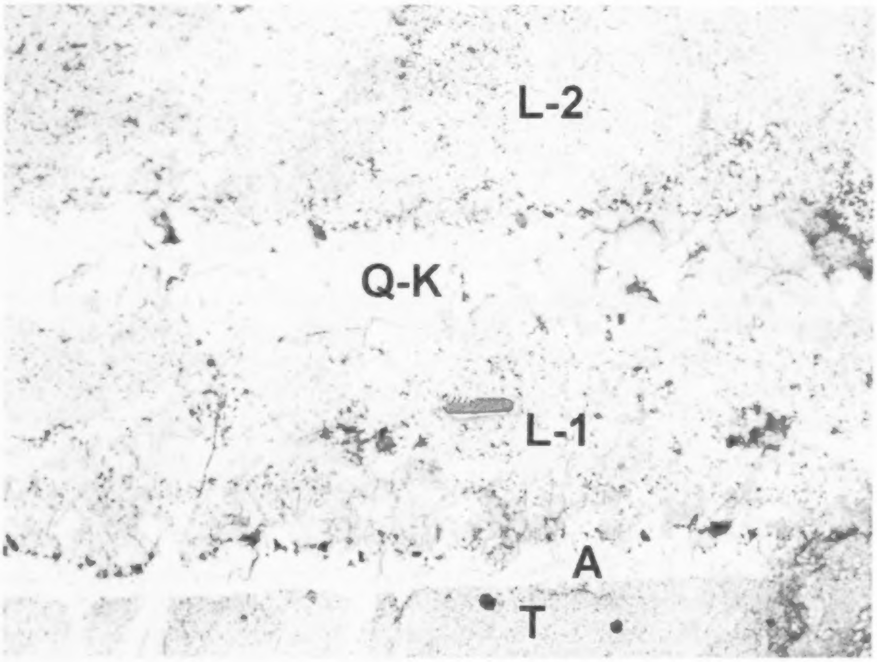

Photo 54. Zonation in the Case North Dike adjacent to southern contact with tonalite host rocks (T). Zones from bottom to top: aplite border (A), leucogranite (L-1), quartz + blocky potassium feldspar (Q-K) and repeat of leucogranite unit (L-2).

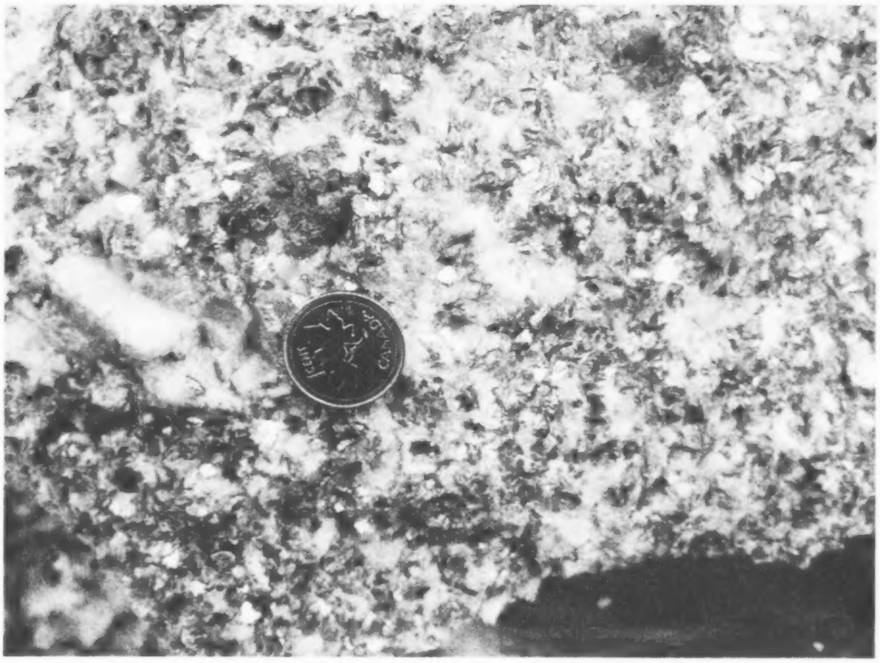

Photo 52. Deep orange spessartine-albite-green muscovite patch, Case Central Dike.

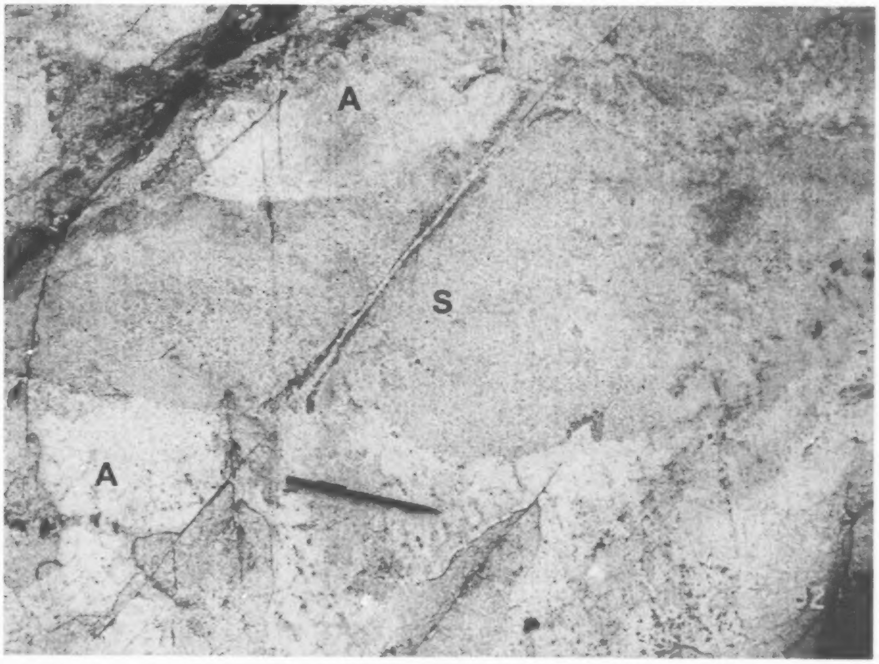

Photo 53. Spodumene granite (S) layered with sodic aplite (A) in the western part of the Case Central Dike.

Late dikes of spodumene pegmatite transect the aplite border zone and progress into the tonalite host rocks, indicating a relatively early solidification for the aplite (*see* Photo 50).

The **western part of the Central Dike** (UTM 578055E 5431567N, Zone 17) exhibits a marked increase in the sodic aplite unit that is typically layered with medium-grained, spodumene granite (Photo 53) and distinctive quartz-ballpeen-texture, dark mica-albite pods. The dark mica is a cesium-bearing muscovite (877 to 1697 ppm Cs) and it occurs with minor fluorapatite and spessartine.

The aplite border zone in the western part contains accessory spessartine, ferrocolumbite, manganocolumbite and fluorapatite. The garnet aplite pods contain minor spessartine and fluorapatite. The spodumene granite, contains fine- to medium-grained green spodumene (20 to 30 volume %), quartz, feldspar, minor muscovite, ferrocolumbite, manganocolumbite, microlite and manganese-rich spessartine, and local green beryl (up to 5 cm).

Geology of Case North Dike

The North Dike (UTM 578131E 5431641N, Zone 17) lies about 10 m north of the Central Dike. It is characterized by layering parallel to its strike (Photo 54) and consists of the following pegmatite zones:

- garnet aplite border zone
- granitic zone (quartz-muscovite-potassium feldspar with minor spessartine)
- aplite pods with minor manganese-rich spessartine
- quartz-rich core zone with euhedral white potassium feldspar
- spodumene-rich zone (muscovite-potassium feldspar-quartz-spodumene)

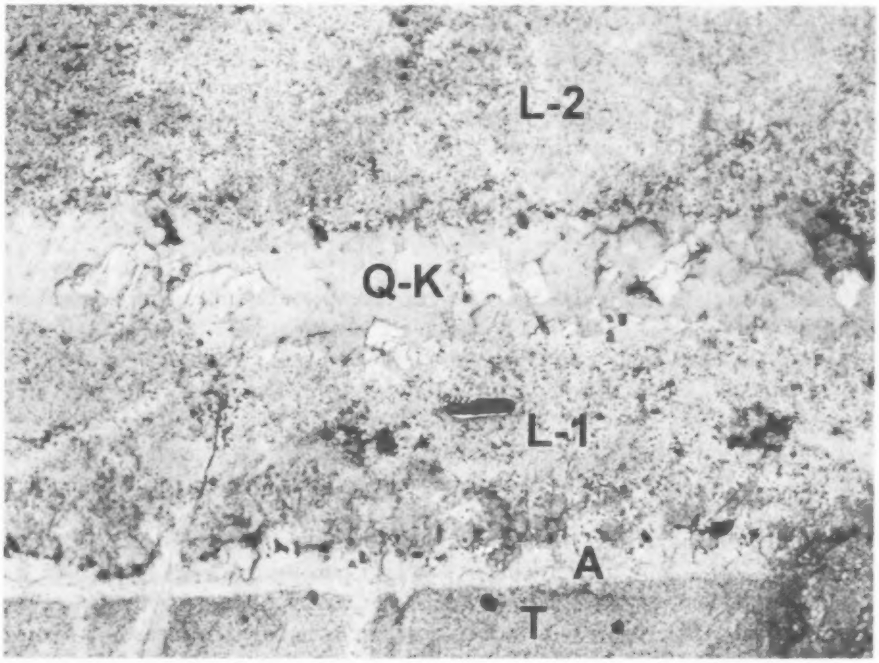

Photo 54. Zonation in the Case North Dike adjacent to southern contact with tonalite host rocks (T). Zones from bottom to top: aplite border (A), leucogranite (L-1), quartz>>blocky potassium feldspar (Q-K) and repeat of leucogranite unit (L-2).

Local green beryl occurs along the contact between the aplite border zone and a thin quartz-rich layer. Rare, steel-blue, molybdenite pods (1 to 2 cm diameter) occur in the granitic zone. Aplite pods are rimmed by green muscovite. The spodumene-rich zone contains the largest spodumene blades (5 by 70 cm) in the entire pegmatite group. The spodumene zone contains accessory manganocolumbite to manganotantalite and microlite.

Petrochemistry of Case Pegmatite Dikes

The **South Dike** contains the least evolved bulk and mineral compositions in the Case pegmatite system. The most evolved unit in this dike consists of an albitized potassium feldspar-albite-quartz-muscovite unit from the main eastern outcrop area (*see* Tindle, Selway and Breaks 2006 (MRD 210), Table 12). Its bulk composition contains 8.07 weight % Na_2O and 3.61 weight % K_2O due to the abundance of albitized potassium feldspar, Rb (1594 ppm), Li (499 ppm) and Cs (135 ppm) mainly in green muscovite, Be (61 ppm) in beryl and Nb (277 ppm), Ta (239 ppm) and a Nb/Ta ratio of 1.2 related to ferrocolumbite.

The **Central Dike (west)** has more elevated rare-element contents, particularly in the spodumene granite zone and the dark mica pods (*see* Tindle, Selway and Breaks 2006 (MRD 210), Table 12). The spodumene granite contains Li_2O (1.58 weight %) obviously due to spodumene, Rb (631 ppm) and Cs (172 ppm) due to muscovite; Be (227 ppm) in beryl, and Nb (57 ppm), Ta (58 ppm) and a 1.0 Nb/Ta = 1.0 due to ferrocolumbite and manganocolumbite. An elevated barium content of 482 ppm likely relates to potassium feldspar.

The quartz-ballpeen-textured, dark mica-albite pods contain the highest Rb and Cs contents in the western part of the Central Dike (4349 ppm Rb, 727 ppm Cs) due to the abundance of (Rb, Cs)-bearing muscovite, but lower Li (3342 ppm) with the absence of spodumene. Although the levels of Nb (262 ppm), Sn (128 ppm) and Ta (64 ppm) are higher than the spodumene granite unit and likely due to small amounts of ferrocolumbite and cassiterite, the Nb/Ta ratio of 4.1 indicates a lower degree of evolution than the main exposure of the Central Dike.

The **Central Dike (main outcrop)** contains elevated rare-element contents in the garnet aplite border zone, spodumene zone and the muscovite-rich pods (*see* Tindle, Selway and Breaks 2006 (MRD 210), Table 12). The layered garnet aplite border zone is sodium-rich (8.87 weight % Na_2O) due the abundance of albite and contains 0.84 weight % MnO due to spessartine, and elevated Nb (132 ppm), Ta (73 ppm) and a low Nb/Ta = 1.8.

The muscovite-spessartine-rich pod contains several rare-elements that achieve maximum bulk concentrations for the entire pegmatite system: Rb_2O (1.16 weight %), Cs (1344 ppm), Ga (421 ppm) and Sn (206 ppm) that are mostly contained in (Rb, Cs)-bearing muscovite. Furthermore, the Nb/Ta ratio (0.6) is the lowest observed in any unit of the pegmatite and indicates extreme evolution.

HOST ROCK DISPERSION HALOS

Bulk samples of the biotite tonalite host rock were collected with increasing distance from the southern contact of the North Dike as summarized in Table 12 (*see* Tindle, Selway and Breaks 2006 (MRD 210)). These data indicate that dispersion of beryllium, lithium, niobium, rubidium and tin occurred at least within 1.35 m of the North Dike contact. In particular, rubidium contents decrease rapidly from 809 ppm Rb within 3 cm of the contact to 57 ppm Rb in the 1.3 to 1.35 cm sample interval, and this corresponds to an appreciable rise in the K/Rb ratio (19 to 280). Metals of limited mobility such as beryllium, niobium and tin (Beus et al. 1968) show a subtle concentration in the host rocks within 3 cm of the contact.

Lithium dispersion is also evident by an increase from 51 ppm to progressively higher values in the 3 more distant samples (353 to 405 ppm Li). Lithium typically forms the most extensive exomorphic halos around lithium-rich pegmatites (Beus et al. 1968); however, the 4 samples selected in this study are insufficient to characterize its full extent. In the Dryden area, Breaks (1989) found that lithium exomorphic aureoles can by up to 400 m thick at a lithium concentration of 100 ppm, albeit in host rocks of a different composition (mafic metavolcanic rocks).

Subtle mineralogical evidence for pegmatite fluid dispersion is only revealed in the fine-grained muscovite-enriched selvage in tonalite adjacent pegmatite contact. Holmquistite, commonly found in dispersion halos around lithium-rich pegmatites (Breaks, Selway and Tindle 2005), was not encountered in the Case pegmatite system.

Mineral Chemistry of Case Pegmatite Dikes

SOUTH DIKE

Tantalum-Niobium Oxide Minerals

The early aplite dike contains primitive ferrocolumbite that overlap with relatively poorly evolved compositions of the South Dike and the *en échelon* dike (*see* Figure 32a: 17.94 to 18.94 weight % Ta_2O_5).

Oxide minerals in the South Dike and its related *en échelon* dike are mostly ferrocolumbite with subordinate ferrotantalite, with sparse manganocolumbite, manganotantalite and microlite (*see* Figure 32a). The overall compositional field exhibits a ferrocolumbite → ferrotantalite trend similar to the iron-rich suite of Tindle, Breaks and Webb (1998). The most evolved oxides ultimately fall in the manganotantalite field (*see* Figure 32a), as found in grains of the *en échelon* dike that exhibit patchy zonation with a wide range of compositions (02-JBS-118-13: 28.5 to 70.8 weight % Ta_2O_5). Microlite locally replaces ferrocolumbite at 02-JBS-118-11and contains 65.0 to 69.6 weight % Ta_2O_5.

Garnet

The orange garnet is generally spessartine rich (40 to 70%) with subordinate almandine (28 to 56%). Garnets are commonly zoned with spessartine-rich cores and calcium-bearing, almandine iron-rich spessartine rims. For example, 02-JBS-118-12B from the quartz-coarse muscovite zone contains euhedral orange garnet (1 mm in diameter) with spessartine-rich cores (60% spessartine, 38% almandine) and calcium-bearing almandine-dominant rims (56% almandine, 40% spessartine, 3% grossular). The fluorapatite is also enriched in MnO (0.48 to 2.91 weight %). In the *en échelon* dike, the garnet is slightly zoned with and an iron-rich, spessartine core (56% spessartine, 42% almandine, 2% grossular) and a spessartine rim (60% spessartine, 39% almandine). This is the reverse of the garnet zoning documented in the rest of the South Dike.

Beryl

The green beryl contains a modest Na_2O (0.95 to 1.89 weight %) and Cs_2O content (0.14 to 0.76 weight %) that is similar to the Central Dike (west part) as summarized in Table 13. Cores of such beryl are slightly enriched in Cs_2O and lower Na_2O than the crystal rims.

Table 13. Cesium and sodium contents (weight % oxide) in beryl from various units of the Case pegmatite system.

Pegmatite Zone	Sample #	Cs_2O (rim)	Cs_2O (core)	Na_2O (rim)	Na_2O (core)
Case South Dike					
Green beryl in albite-muscovite-quartz pod	02-JBS-118-03	0.30–0.34	0.76	1.29–1.77	1.89
Case Central Dike (west part)					
Green beryl in spodumene granite	02-JBS-123-05	0.37	0.47	1.40	1.73
Case Central Dike (eastern outcrop)					
Green beryl in aplite border zone	02-JBS-115-06	0.91–1.63	0.64–1.07	1.25–1.73	1.78–1.90
Blue to white beryl in spodumene zone	02-JBS-115-04	3.69–4.54	2.94–3.06	1.43–1.54	0.99–1.53

Table 14. Rubidium, cesium, K/Cs and K/Rb in potassium feldspar bulk compositions from the Case pegmatite.

Sample #	Rb (ppm)	Cs (ppm)	K/Cs	K/Rb
South Dike				
Case 97KF-4	3807	155	715	29
Case 97KF-5	3932	182	604	27
02-JBS-116-01	3880	105	1120	30
02-JBS-116-02	4080	175	663	28
02-JBS-116-03	4000	128	923	30
02-JBS-118-02	4427	198	602	30
02-JBS-118-06	7609	171	767	15
02-JBS-118-14	3659	168	677	31
Mean	4424	160	759	28
Central Dike (West part)				
01-FWB-154	5312	229	526	23
01-FWB-157-02	4774	209	563	25
Mean	5043	219	545	24
Central Dike (Main exposure)				
Case 97KF-1	5448	350	313	20
Case 97KF-2	6309	560	194	17
02-JBS-123-07	4754	345	342	25
02-JBS-123-09	5183	387	301	22
Mean	5424	410	288	21
North Dike				
Case 97KF-3	9593	1871	62	12
01-JBS-98-03	11104	1990	58	10
01-JBS-98-05	7106	1000	113	16
Mean	9268	1620	78	13

Potassium Feldspar

The early aplite dikes, postdated by the Case South Dike, contain potassium feldspar that is BaO rich (0.37 to 2.07 weight %) and Rb_2O poor (0.02 to 0.07 weight %) relative to the South Dike potassium feldspar compositions (*see* Tindle, Selway and Breaks 2006 (MRD 210), table with electron microprobe data (folder "Probe Data")). The South Dike contains significantly higher Rb and Cs in bulk potassium feldspars (respective averages of 4424 and 160 ppm: Table 14).

CENTRAL DIKE (WEST PART)

Tantalum-Niobium Oxide Minerals

The oxides in the aplite border zone and spodumene granite in the Central Dike West are mostly ferrocolumbite and manganocolumbite with minor ferrotantalite and manganotantalite. These minerals average 33.25 weight % Ta_2O_5, but have a wide range in Ta_2O_5 (13.84 to 59.62 weight %). Similarly, the Mn/(Mn+Fe) ratios span a large range of 0.11 to 0.61. The fine-grained oxide minerals in the garnet aplite border zone are mostly ferrocolumbite with a thin manganocolumbite rims.

The spodumene granite (01-FWB-159-01) contains grains with relic cores of ferrocolumbite (Ta_2O_5 = 22.10 to 31.86 weight %) mantled by ferrotantalite rims (Ta_2O_5 = 51.42 to 53.68 weight %). These phases were overprinted by patches of ferrocolumbite (Ta_2O_5 = 39.69 weight %) and manganocolumbite (Ta_2O_5 = 45.08 weight %).

The aplite zone (01-FWB-160-03) contains zoned grains with manganotantalite cores (Ta_2O_5 = 51.65 to 54.75 weight %), intermediate zones of manganocolumbite (Ta_2O_5 = 46.45 to 49.68 weight %) and ferrocolumbite (Ta_2O_5 = 48.95 to 51.11 weight %) overlapped by a ferrotantalite rim (Ta_2O_5 = 58.98 to 59.62 weight %).

Garnet

The dominantly spessartine-rich (53 to 68% spessartine, 28 to 44% almandine) orange garnet is commonly zoned with manganese-rich cores and iron- and calcium-rich rims. The quartz-dark mica-albite pods (01-FWB-160-02) contains zoned spessartine with a manganese-rich core (60% spessartine, 35% almandine) and a iron- and calcium-rich rim (56% spessartine, 32% almandine, 10% grossular).

Fluorapatite

The green fluorapatite contains moderate amounts of MnO (0.26 to 1.81 weight %).

Muscovite and Potassium Feldspar

Muscovite, analyzed by the electron microprobe, is enriched in Rb_2O (0.47 to 1.07 weight %) and Cs_2O (0.02 to 0.49 weight %). A slight zonation of these elements is evident in muscovite from the aplite border zone (01-FWB-156) where the core contains lower Rb_2O (0.62 to 0.67 weight %) and Cs_2O (0.04 to 0.06 weight %) relative to the rim (Rb_2O = 0.82 to 0.87 weight % and Cs_2O = 0.49 weight %).

Two bulk compositions of potassium feldspar (*see* Table 14) reveal a greater degree of evolution relative to the South Dike as indicated by higher mean Rb and Cs (5043 and 219 ppm, respectively).

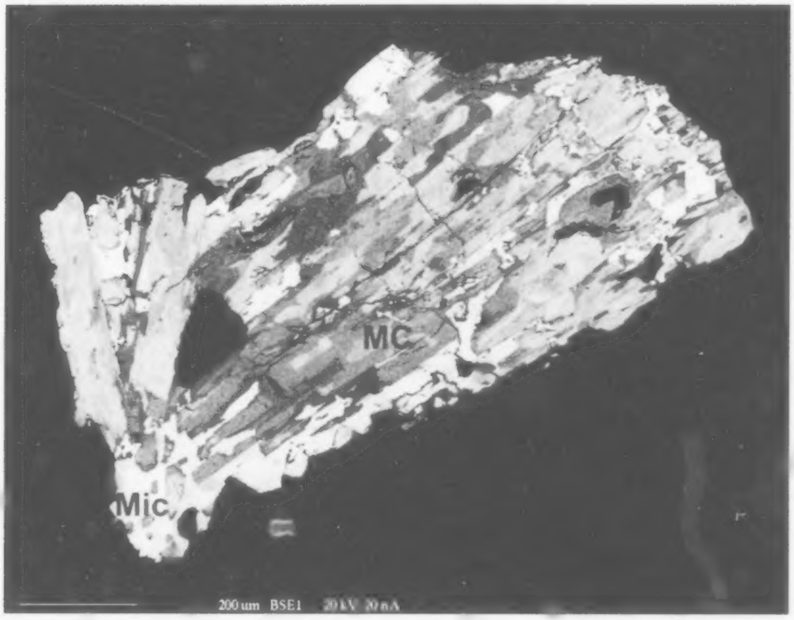
MC
Mic
200um BSE1 20kV 20nA

Photo 55. Manganocolumbite from the main eastern exposure of the Case Central Dike. Note the very complex texture that involves patchy zoned manganocolumbite (MC) replaced by patches and veins of microlite (Mic).

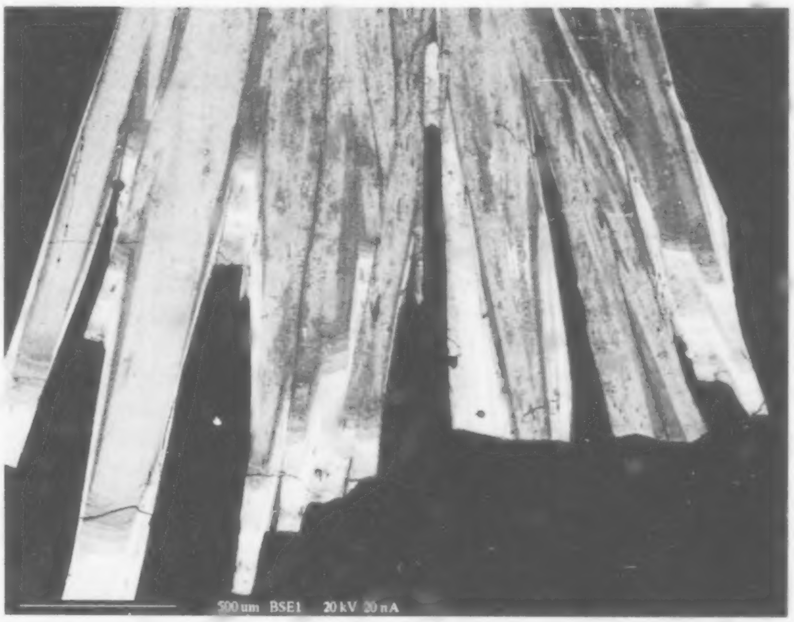
500um BSE1 20kV 20nA

Photo 56. Radiating cluster of progressively zoned, manganocolumbite to manganotantalite from the Case North Dike at 01-JBS-97-12.

CENTRAL DIKE (MAIN EASTERN OUTCROP)

Tantalum-Niobium Oxide Minerals

Compositional variation of the Nb-Ta oxide phases in the main exposure of the Central Dike is shown in Figure 32b. A shift in Mn/(Mn+Fe) ratios is notable for most of the data as compared to the South Dike and Central Dike (west part), such that the compositions mainly fall into the more evolved manganocolumbite and manganotantalite quadrants.

The blocky, bladed and platy oxide minerals in the spodumene zone of the Central Dike are mostly manganocolumbite and manganotantalite with minor ferrocolumbite and ferrotantalite. The oxide minerals may form radiating clusters of needle-like crystals obvious on outcrop surface (*see* Photo 51) and contain an average of 42.13 weight % Ta_2O_5 (range 22.65 to 67.16 weight % Ta_2O_5). In polished sections, these minerals more commonly exhibit complex patchy zonation with internal and marginal replacement by microlite (Ta_2O_5 from 53.49 to 73.77 weight %). A good example of such textural relations is found at 01-JBS-97-04A where manganocolumbite (38.71 to 51.46 weight % Ta_2O_5) with patches of manganotantalite (54.45 to 58.39 weight % Ta_2O_5) is partially replaced by microlite (Photo 55).

The quartz-rich core zone contains the most evolved oxide compositions in the entire Case pegmatite system (*see* Figure 32b). These comprise blocky to bladed manganotantalite and minor manganocolumbite with 35.82 to 69.63 weight % Ta_2O_5 and Mn/(Mn+Fe) = 0.56 to 0.86.

Progressively zoned manganotantalite (58.50 to 69.63 weight % Ta_2O_5) occurs as blades as at 01-JBS-97-12 (Photo 56). Most of the blades are zoned parallel to the main direction of growth as marked by an overall increase in tantalum content toward the tips of the blades. Microlite (65.69 to 73.71 weight % Ta_2O_5) occurs as isolated, apparently primary grains in the quartz-rich core.

Garnet

The orange garnet in the garnet aplite pods, spodumene zone and quartz-rich core zone is mainly spessartine (56 to 69% spessartine) with significant iron-enrichment (27 to 42% almandine). Manganese-rich spessartine (68 to 69% spessartine) also occurs as inclusions within green spodumene. Garnet with the highest spessartine component occurs in the green muscovite-rich pod (01-JBS-97-14) where a zonation between a manganese-rich core (86% spessartine, 12% almandine) and a more iron-rich rim (65 to 66% spessartine, 31 to 32% almandine) was detected.

Fluorapatite

The blue fluorapatite in the garnet aplite pods contains moderate amounts of MnO (0.73 to 1.53 weight %).

Beryl

Beryl from the spodumene zone of the Central Dike is the most evolved in the entire Case pegmatite system. Green and blue to white beryl crystals, respectively from the aplite border and spodumene zones, as summarized in Table 13, reveal a core to rim zonation that marks an increase in Cs_2O and a decrease in Na_2O. Cs_2O attains high levels of 3.7 to 4.5 weight % in the spodumene zone that are comparable to beryl compositions from the innermost zones of the pollucite-bearing Tanco pegmatite (Černý, Ercit and Vanstone 1996, p.24). The beryl composition data from the Central Dike, therefore, add further support for the possible presence of pollucite.

Table 15. Rare-element content and selected element ratios in muscovite bulk compositions from the Case complex-type, spodumene-subtype pegmatite and potassic pegmatite from Case batholith.

Sample #	Be (ppm)	Cs (ppm)	Li (ppm)	Nb (ppm)	Rb (ppm)	Sn (ppm)	Ta (ppm)	K/Cs	K/Rb	Nb/Ta
Case complex-type, spodumene-subtype pegmatite										
Central pegmatite dike										
97-MZ-MU-1	22	1380	3532	408	9080	240	161	62	9.5	2.5
97-MZ-MU-2	20	1400	3488	363	9100	241	151	62	9.5	2.4
01-JBS-97-01	17	1066	3447	322	9365	256	161	78	8.9	2.0
01-JBS-97-16	17	1043	3093	325	9096	240	155	80	9.2	2.1
01-JBS-97-28	17	961	3366	337	9055	237	150	85	9.1	2.5
Mean	18.6	1170	3385	351	9139	243	156	73	9.2	2.3
South pegmatite dike										
02-JBS-116-07	17.4	340	2237	452	4980	476	69	252	17.2	6.5
02-JBS-118-12	19.8	372	2373	418	4625	519	59	232	18.7	7.1
Mean	18.6	356	2305	435	4803	498	64	242	18.0	6.8
Garnet-biotite-muscovite potassic pegmatite dike in Case batholith										
02-JBS-120-02	6.0	28	768	348	1026	152	17	3121	85	20.5

Muscovite and Potassium Feldspar

The bulk compositions of potassium feldspar from the Central Dike (*see* Tindle, Selway and Breaks 2006 (MRD 210), Table 12) indicate an eastward increase in pegmatite evolution from the more sodic western part of the dike to the main eastern exposure. This trend is most clearly revealed by the respective increases in average Rb (5424 ppm versus 5043 ppm) and average Cs (410 ppm versus 219 ppm) as summarized in Table 14.

Muscovite bulk compositions were only obtained from the main exposure of the Central Dike and the South Dike (Table 15). These compositions reveal significantly higher average cesium, rubidium, lithium and tantalum in the main eastern exposure of the Central Dike, but lower niobium and tin relative to the less evolved South Dike. The tantalum content of muscovite from the Central Dike (150 to 161 ppm) indicates a greater degree of melt evolution than the South Dike (59 to 64 ppm). This is corroborated by a more highly fractionated Nb/Ta ratio in muscovite (*see* Table 15) from the Central Dike (mean = 2.3) versus the South Dike (mean = 6.8). The tantalum levels in muscovite from the Central Dike are similar to the range for the North Aubry pegmatite (*see* Table 7: 129 to 165 ppm).

NORTH DIKE

Tantalum-Niobium Oxide Minerals

The acicular to bladed oxide minerals in the spodumene zone of the North Dike (*see* Figure 32b) consist of manganocolumbite (32.85 to 47.78 weight % Ta_2O_5) and manganotantalite and rare ferrotantalite (52.93 to 68.98 weight % Ta_2O_5). The average tantalum content for oxide minerals in the spodumene zone is 55.97 weight % Ta_2O_5. The Mn/(Mn+Fe) has an average of 0.60 and a range from 0.47 to 0.77. The oxide minerals exhibit patchy and oscillatory zoning that occasionally mantle microlite (76.87 to 77.26 weight % Ta_2O_5). Microlite also occurs as an infilling between abundant spodumene blades that indicates its late-stage crystallization.

Garnet

The fine-grained orange garnet in the aplite pod and quartz-rich core zone is spessartine-rich (59 to 69% spessartine, 27 to 39% almandine).

Potassium Feldspar

Maximum levels of Rb (7106 ppm to 1.11 weight %) and Cs (1000 to 1871 ppm) and lowest K/Rb and K/Cs ratios, indicative of the highest degree of evolution occur in the North Dike (*see* Table 14). Both the rubidium and cesium contents fall within the ranges for blocky potassium feldspar from the Bernic Lake pegmatite group of Manitoba, which hosts the Tanco pegmatite (Černý et al. 1981, p.93).

SUMMARY OF MINERAL CHEMISTRY

The composition of the tantalum-oxide minerals in the Case pegmatite can be used to infer the crystallization sequence of the dikes. With increasing fractionation of the pegmatite-forming melt, the columbite group minerals show an increase in manganese and tantalum content in the following series:

- South Dike: least evolved ferrocolumbite (average 0.42 Mn/(Mn+Fe), 24.95 weight % Ta_2O_5
- Central Dike West: ferrocolumbite and manganocolumbite with higher average Ta_2O_5 (average 33.25 weight %) and Mn/(Mn+Fe) = 0.48
- Central Dike and North Dike spodumene zones: more evolved manganocolumbite to manganotantalite with average Mn/(Mn+Fe) = 0.60, and average Ta_2O_5 of 42.13 and 55.97 weight %, respectively
- Central Dike quartz-rich core zone: most evolved manganotantalite average Mn/(Mn+Fe) = 0.73 and Ta_2O_5 = 59.43 weight %

The overlapping compositional fields for each dike support the presence of a common pegmatite-forming melt.

Microlite occurs throughout the Case pegmatite as sparse, primary grains and more commonly as isolated patches along the margins of columbite-tantalite crystals as an alteration product, infilling between spodumene blades in the North Dike. This indicates that most microlite crystallized from late-stage tantalum-, calcium- and fluorine-rich fluids.

The composition of the garnet, potassium feldspar and beryl in the Case pegmatite indicates a similar crystallization sequence to that concluded from compositional variation of the Ta-Nb oxide minerals. The garnets range in composition from almandine to spessartine in the South Dike to spessartine with increasing manganese content from the Central Dike West to Central Dike to North Dike. The garnets throughout the Case pegmatite system have manganese-rich cores and iron- and calcium-rich rims that suggest an increase in iron and calcium in the late-stage fluids.

Petrogenesis of Case Pegmatite Dikes

The South, Central and North Dikes are genetically related and judged to have formed by continuous fractionation of a peraluminous pegmatite-forming melt, as all 3 dikes are proximal and exhibit similarities in their mineralogy. These dikes have a garnet aplite border zone, quartz-muscovite-white feldspar granitic zone (albite in South Dike and potassium feldspar in Central and North Dike), garnet aplite pods, spodumene zone (not present in the South Dike) and blocky potassium feldspar-quartz core.

The presence of muscovite and potassium feldspar and absence of spodumene indicates that the South Dike crystallized from a granitic melt with low lithium contents, low acidity and a range in salinity (London 1982). The abundant spodumene, potassium feldspar and muscovite in the Central and North Dikes indicate crystallization from a granitic melt with moderate lithium content, low acidity and a range in salinity (London 1982).

The facts that the Central and North Dikes are spodumene-subtype, coupled with absence of either petalite or "squi" (acronym for spodumene-quartz intergrowth after petalite), indicate crystallization at pressures greater than 2 kilobars at moderate temperatures (London 1984). Widespread spessartine-rich garnet and muscovite distributed throughout the Case pegmatite system indicates crystallization from a peraluminous and H_2O-rich melt. The fluorine content in the Case pegmatite is judged to be moderate to low as the main fluorine-bearing phase, fluorapatite is common in the South Dike, but occurs more sparsely in aplite from the Central Dike. Microlite, another fluorine-bearing phase, is sparse throughout the Case pegmatite and, thus, would not contribute significantly to the fluorine content of bulk rocks. Boron was not an important volatile component in the pegmatitic melt as tourmaline is completely absent in the Case pegmatites and also was not encountered as an exomorphic phase in the tonalite host rocks.

Assuming all dikes are from the same parental magma that evolved by normal fractional crystallization processes, the following northward sequence of evolution is proposed: South dike → Central dike (west) → Central Dike (spodumene zone) → North Dike (spodumene zone) → Central Dike (quartz-rich core zone).

The Ta-Nb oxide compositions change (*see* Figures 32a and 32b) from dominantly ferrocolumbite (South Dike) to ferrocolumbite and manganocolumbite (Central Dike West) to manganocolumbite and manganotantalite in the Central Dike (east part) and North Dikes. The most evolved manganotantalite composition occurs in the quartz-rich core zone of the Central Dike. The garnet compositions evolve from almandine to spessartine in the South Dike to spessartine with increasing Mn content from the Central increasing evolution as revealed by its rubidium and cesium contents and the K/Rb ratio from South to Central to North Dikes. This fractionation trend is also supported by bulk compositions of potassium feldspar and muscovite that show progressive increase in rubidium and cesium contents and decrease in K/Cs and K/Rb ratios. The beryl compositions also follow the same trend with increasing cesium contents from South Dike to Central Dike West to Central Dike.

Metasomatism of the host biotite tonalite host rock is subtly evident along its contact with the pegmatite dikes as marked by abundant green muscovite, whereas the unaltered tonalite less than 1 m away from the pegmatite contains biotite as the sole mica mineral. Rare-element contents (i.e., Rb, Cs, and Nb) decrease and barium and strontium contents increase in the biotite tonalite with increasing distance from the contact with the pegmatite dikes, which indicates that rare-element enriched fluids migrated from the pegmatite into the host rock.

The lack of significant levels of the rare-elements, particularly lithium, in the metasomatized tonalite, however, suggests that most of these metals were retained within the pegmatite-forming melt. This is in contrast to lithium-rich pegmatites hosted in highly reactive rocks such as mafic metavolcanic rocks documented elsewhere in the Superior Province as in the Dryden area. Here, extensive lithium-dispersion halos are evident (up to 2.4 weight % Li_2O) in holmquistite-bearing, metasomatized host-rocks (Breaks 1989).

The South, Central and North Dikes are genetically related and probably formed by continuous fractionation of a peraluminous pegmatite-forming melt, as all 3 dikes are proximal and exhibit similarities in their mineralogy and chemical trends in bulk rock and mineral compositions.

MINERAL EXPLORATION RECOMMENDATIONS

The pattern of rare-element pegmatite evolution reveals a progression from beryl-type to complex-type, spodumene-subtype pegmatite that is supported by the chemistry of potassium feldspar, beryl, garnet and the Ta-Nb oxide phases. The south to north fractionation trend infers that there is potential for even more evolved, cesium- and tantalum-enriched pegmatites to the north of the North Dike within an area of poor exposure. This area is highly recommended for follow-up exploration.

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Appendix 1

Definitions of Common Pegmatite Terms

Appendix 1. Definitions of common pegmatite terms.

A/CNK	a molecular ratio of $Al_2O_3/(CaO + Na_2O + K_2O)$ calculated from bulk whole rock analyses. A/CNK = (wt % Al_2O_3 in sample/101.96128)/[(wt % CaO in sample/56.08) + (wt % Na_2O in sample/61.979) + (wt % K_2O in sample/94.197)]
albitization	fine-grained white albite crystallizes along the rims and cleavage planes in the potassium feldspar due to alteration by late-stage fluids
Apfu or *apfu*	atoms per formula unit. *Apfu* are the units for the tiny subscripted numbers in a mineral chemical formula, e.g., the formula for almandine garnet is $Fe_3Al_2Si_3O_4$, which indicates that the mineral contains 3 *apfu* of iron, 2 *apfu* of aluminum, 3 *apfu* of silicon and 4 *apfu* of oxygen.
aplite	mostly composed of fine-grained equant white albite (sodium-plagioclase) with accessory minerals of quartz, garnet, tourmaline, green muscovite, tantalum-oxide minerals and fluorapatite
cleavelandite	textural term referring to albite plagioclase with a platy habit
electron microprobe	analytical equipment that is capable of analyzing the composition of a 1-2 µm spot on a mineral grain usually defocussed to 10-20 µm to avoid sample damage
end-member	a unique ideal composition of a mineral
evolved	a rock that has experienced a significant amount of fractionation before it crystallized, e.g., a pegmatite rich in cesium
exocontact	the chemically altered host rock surrounding a pegmatite. The exocontact commonly ranges in width from 1 cm to 1 m
fertile granite	the parental granite to rare-element pegmatite dikes
fractionation	a magmatic differentiation process in which the magma is depleted in elements that enter the crystal structure of the solid crystals and enriched in elements that remain in the liquid. Increasing fractionation will result in a liquid enriched in rare-elements (e.g., Li, Cs, Ta).
graphic	intergrowth of a mineral with quartz, usually potassium feldspar with numerous quartz inclusions
greisen	a rock composed of approximately 50 volume % quartz and 50 volume % muscovite
leucogranite	a rock that contains 2 feldspars (plagioclase and potassium feldspar), quartz, mica and Al-rich minerals (e.g., garnet and tourmaline)
metasomatized host rocks	alteration of the composition of the pegmatite's host rock due to an influx of rare-element-enriched fluids. The host rock becomes enriched in highly mobile alkali elements (i.e., Li, Rb, Cs) and volatile components (i.e., B, F).
pegmatite zone	a volume of rock within an individual pegmatite that can distinguished from the rest of the pegmatite by its mineralogy and/or texture
peraluminous	Al-rich rock (A/CNK > 1.0)
plumose muscovite	muscovite + quartz intergrowth
potassic pegmatite	a rock that consists of blocky white potassium feldspar, books of muscovite and quartz
primitive	a rock that has experienced very little fractionation before it crystallized, e.g., a granite rich in magnesium and calcium
rare-element	Li, Rb, Cs, Nb, Ta, Sn, F, B, Be, Tl, Ge
rare-element pegmatite	very coarse-grained granite with rare-element-rich minerals (e.g., beryl, tourmaline, spodumene, tantalum-oxides) and pegmatitic textures (e.g., aplite, graphic intergrowths, internal zoning)

Appendix 2

Factors for Conversion for Various Rare-Elements

Appendix 2. Factors for conversion for various rare-elements in ppm to weight % rare-element oxide, with example calculations.

Weight % Rare Element	**Conversion Factor**	**Weight % Rare Element Oxide**
Beryllium (e.g., 0.50 % Be)	2.778	0.50% × 2.778 = 1.39 wt % BeO
Cesium (e.g., 500 ppm Cs)	1.060	500 ppm = 0.05% × 1.060 = 0.053 wt % Cs_2O
Lithium (e.g., 2.55 % Li)	2.152	2.55% × 2.152 = 5.49 wt % Li_2O
Niobium (e.g., 325 ppm Nb)	1.431	325 ppm = 0.0325% × 1.431 = 0.0465 wt % Nb_2O_5
Tantalum (e.g., 755 ppm Ta)	1.221	755 ppm = 0.0755% × 1.221 = 0.092 wt % Ta_2O_5
Rubidium (e.g., 15 000 ppm = 1.5% Rb)	1.099	1.5% × 1.099 = 1.65 wt % Rb_2O

Element ppm / 10 000 = element %; element % × conversion factor = oxide wt %.

Appendix 3

Common Pegmatite Minerals Found in the Superior Province, Ontario, from this Study

Appendix 3. Common pegmatite minerals found in Superior Province, Ontario in this study.

Pegmatite Minerals Found in Ontario

Mineral	Species	Simplified Composition	Formula
Amblygonite		Li-phosphate	$LiAlPO_4(F,OH)$
Apatite	- Fluorapatite	F-apatite	Ca5(PO4)3(F,OH)
Beryl		Be-silicate	$Be_3Al_2Si_6O_{18}$
Cassiterite		Sn-oxide	SnO_2
Columbite-Tantalite	- Ferrocolumbite	(Fe,Nb)-oxide	$FeNb_2O_6$
	- Ferrotantalite	(Fe,Ta)-oxide	$FeTa_2O_6$
	- Manganocolumbite	(Mn,Nb)-oxide	$MnNb_2O_6$
	- Manganotantalite	(Mn,Ta)-oxide	$MnTa_2O_6$
Cordierite			$(Mg,Fe)_2Al_4Si_5O_{18}$
Feldspar	- Albite	Na-plagioclase	$NaAlSi_3O_8$
	- Potassium feldspar	K-feldspar	$KAlSi_3O_8$
Ferrotapiolite		(Fe,Ta)-oxide	$FeTa_2O_6$
Fluorite			CaF_2
Holmquistite (in host rocks)		Li-amphibole	$Li_2(Mg,Fe^{2+})_3Al_2Si_8O_{22}(OH)_2$
Gahnite		Zn-oxide	$ZnAl_2O_4$
Garnet	- Almandine	Fe-garnet	$Fe_3Al_2(SiO_4)_3$
	- Spessartine	Mn-garnet	$Mn_3Al_2(SiO_4)_3$
	- Grossular	Ca-garnet	$Ca_3Al_2(SiO_4)_3$
	- Pyrope	Mg-garnet	$Mg_3Al_2(SiO_4)_3$
	- Andradite	(Ca,Fe)-garnet	$Ca_3Fe^{3+}{}_2(SiO_4)_3$
Liberite		(Li,Be)-silicate	Li_2BeSiO_4
Lithiophilite		(Li,Mn)-phosphate	$LiMnPO_4$
Mica	- Muscovite		$KAl_2(Si_3Al)O_{10}(OH,F)_2$
	- Lepidolite	Li-mica	$K(Li,Al)_3(Si,Al)_4O_{10}(F,OH)_2$
	- Zinnwaldite	(Li, Fe)-mica	$K(LiAlFe^{2+})(AlSi_3)O_{10}(F,OH)_2$
	- Siderophyllite	Fe-biotite	$K(Fe^{2+}{}_2Al)(Al_2Si_2)O_{10}(F,OH)_2$
	- Biotite		$K(Mg,Fe^{2+})_3(Al,Fe^{3+})Si_3O_{10}(OH,F)_2$
	- Phlogopite	Mg-biotite	$KMg_3(AlSi_3)O_{10}(F,OH)_2$
	- Nanpingite	Cs-mica	$Cs(Al,Mg,Fe^{2+},Li)_2(Si_3Al)O_{10}(OH,F)_2$
Microlite		(Ca,Ta)-oxide	$(Na,Ca)_2Ta_2O_6(O,OH,F)$
Molybdenite		Mo-sulphide	MoS_2
Montebrasite		Li-phosphate	$LiAlPO_4(OH,F)$

Appendix 3. Continued

Pegmatite Minerals Found in Ontario

Mineral	**Species**	**Simplified Composition**	**Formula**
Petalite		Li-aluminosilicate	$LiAlSi_4O_{10}$
Pollucite		Cs-aluminosilicate	$(Cs,Na)AlSi_2O_6 \cdot nH_2O$
Quartz			SiO_2
Rutile		Ti-oxide	TiO_2
Spodumene		Li-aluminosilicate	$LiAlSi_2O_6$
Tantalian rutile		(Ti,Ta,Nb)-oxide	$(Ti,Ta,Fe^{3+})_3O_6$
Tourmaline	- Schorl	(Na,Fe)-tourmaline	$NaFe_3Al_6(BO_3)_3Si_6O_{18}(OH)_4$
	- Dravite	(Na,Mg)-tourmaline	$NaMg_3Al_6(BO_3)_3Si_6O_{18}(OH)_4$
	- Elbaite	(Na,Li)-tourmaline	$Na(Al,Li)_3Al_6(BO_3)_3Si_6O_{18}(OH)_4$
	- "Fluor-elbaite"	(Na,Li,F)-tourmaline	$Na(Al,Li)_3Al_6(BO_3)_3Si_6O_{18}(OH)_3F$
	- Foitite	Fe-tourmaline	$\square(Fe_2Al)Al_6(BO_3)_3Si_6O_{18}(OH)_4$
	- Uvite	(Ca,Mg)-tourmaline	$CaMg_3(Al_5Mg)(BO_3)_3Si_6O_{18}(OH)_3F$
	- Feruvite	(Ca,Fe)-tourmaline	$CaFe_3(Al_5Mg)(BO_3)_3Si_6O_{18}(OH)_3F$
Wodginite		(Mn,Sn,Ta)-oxide	$MnSnTa_2O_8$
Zircon		Zr-silicate	$ZrSiO_4$

□ = vacancy at the *X*-site in tourmaline

Appendix 4

Physical Properties of Common Pegmatite Minerals Found in Ontario

Appendix 4. Physical properties of common pegmatite minerals found in Ontario.

Mineral	Important Physical Properties
Albite	White, light pink and occasionally with "moonstone" appearance due to peristerite intergrowth. Transparent to translucent. Hardness 6 to 6.5. Albite has distinctive striations due to polysynthetic twinning that distinguishes the mineral from potassium feldspar of similar colour. Albite can occur as coarse blocky crystals in the quartz-rich core zone of sodic pegmatites or in graphic intergrowths with quartz. The cleavelandite variety of albite is very common in rare-element pegmatites where it is evident as radiating masses of tabular crystals.
Almandine and Spessartine Garnet	Euhedral, dodecahedral (diamond-shaped faces) or trapezohedral crystals are common; also occurs as rounded grains and in massive aggregates. Colour for almandine is red to magenta; spessartine has a distinctive orange. Luster is vitreous and hardness 7 to 7.5.
Amblygonite	Found as coarse subhedral crystals and rounded nodules. Colour is typically milky white but also light yellow; transparent to translucent. Luster is greasy to vitreous. Three cleavages (distinct to perfect). Crystal shape and colour may result in misidentification as plagioclase or white potassium feldspar. Amblygonite has lower hardness (5.5 to 6) and recessively weathers with a distinctive chalk-like crust, unlike the feldspars.
Andalusite	Prismatic crystals, fibrous aggregates and granular masses. Commonly light to deep pink in peraluminous granite and pegmatite. However, part or all of the crystals may be replaced by sericite and thus crystal shape of the pseudomorphs is the only means of recognition. Vitreous to dull luster; translucent to transparent. Hardness 6.5 to 7.
Apatite	Commonly found as hexagonal prisms, generally less than 1 cm in diameter. Colour is typically sea-green to blue-green but also includes brown, blue and orange. Transparent to translucent with a vitreous luster. Distinguished from beryl by its lower hardness and recessive weathering with chalk-like rind.
Beryl	Typical as euhedral to subhedral, rectangular-shaped prisms elongate along c-axis and basal hexagonal sections. Colour is variable but typically pale green, white and less commonly yellow, pink and blue. Hardness 7.5 to 8. Cleavage is often indistinct as a basal parting.
Cassiterite	Dark brown to black in Superior Province pegmatites. Luster is a distinctive adamantine to metallic in short prismatic and dipyramidal crystals that a transparent to opaque. Two cleavages present but commonly not apparent due to fine grain size. Hardness 6 to 7.
Columbite-Tantalite	Black, red-brown, black-brown crystals that are prismatic to tabular; also granular and massive. Platy crystals may have striations parallel to c-axis; luster is submetallic; one distinct cleavage. Translucent to opaque. Hardness 6 to 6.5. Fine-grained columbite-tantalite may be confused with black tourmaline of similar grain size. Columbite-tantalite is non-magnetic and hence distinction from magnetite can readily be made in the field.
Cordierite	Pale to dark blue, violet, grey, grey-green, grey-brown; vitreous, transparent to translucent. Hardness 7 to 7.5. Cordierite is commonly euhedral to subhedral in peraluminous granite and rare-element pegmatite in which rectangular to distinctive pseudohexagonal sections may be observed. Cordierite is susceptible to hydrothermal alteration and can be completely replaced by a soft intergrowth of secondary chlorite, muscovite, garnet and rare beryl. In this case, crystal shape of the cordierite pseudomorphs is the only means of mineral identification.
Ferrotapiolite	Black to brown, generally fine grained and typically intergrown with other black, Ta-Nb-bearing oxide phases. Hence, identification usually based upon electron microprobe analysis. Luster is submetallic, adamantine and resinous. Hardness 6 to 6.5.
Holmquistite	Slender, needle-like prisms and mats of radiating fibrous crystals with distinctive violet to deep blue colouration. Vitreous luster, hardness 5 to 6 and two cleavages intersecting at 54 and 126 degrees that usually are only seen in thin section. Generally found in mafic metavolcanic host rocks within 100 m of a rare-element pegmatite body.

Appendix 4. Continued

Mineral	Important Physical Properties
Lepidolite	Typically occurs as purple to pink fine grained aggregates; may also be colourless, white, grey and yellow. Well-formed pseudohexagonal crystals are rare. Luster pearly to vitreous. Hardness 2.5 to 3 and perfect basal cleavage with flexible and elastic sheets.
Microlite	Brown, yellow, green and reddish octahedral crystals and granular masses. Vitreous to greasy, translucent to opaque and rarely transparent. Hardness 6 to 6.5. Microlite is difficult to recognize in the field owing to its fine grain size and common occurrence as late stage replacement patches and veins in primary Ta-Nb-bearing oxide phases.
Molybdenite	Found as tabular and prismatic hexagonal crystals or a scaly aggregates. Metallic luster with lead grey colour and blue-grey streak. Hardness 1 to 1.5. A common accessory mineral in rare-element pegmatites.
Petalite	Typically found as white, irregular masses or less common as tabular crystals elongated along {100} and flattened on {010}. Pink, grey and orange colors are less common. Polysynthetic twinning on {001} may give the false impression that plagioclase is present. However, petalite has only two cleavages ({001} perfect and {201} good that meet at 37 degrees) compared to the three cleavages for plagioclase that meet approximately at right angles.
Pollucite	Colorless, white or grey, vitreous, isometric crystals or more commonly as anhedral masses. Transparent to translucent. Hardness 6.5 to 7. Luster is vitreous to slightly greasy. Difficult mineral to identify in the field due to white color and massive nature that could easily be mistaken for quartz. Pollucite is susceptible to hydrothermal alteration and may be traversed by a polygonal network of mica-rich veins which is distinctive from quartz.
Potassium feldspar	Crystals usually short prismatic, tabular or elongated parallel to a- or c-axis. Commonly light pink but in peraluminous granites and pegmatites the color is typically white; blue grey and green (amazonite) colors less prevalent. Mineral has three cleavages that meet approximately at right angles. Perthitic texture with albite exsolution lamellae (tiger stripes) is widespread.
Rutile	Red, red-brown, brown, yellow and black short prismatic striated crystals. Hardness 6 to 6.5. Metallic to adamantine luster. Transparent to translucent.
Spodumene	Long prismatic crystals typically flattened and striated parallel to {100}. Colors most commonly pale green but also white, pink and orange. Luster is vitreous and pearly along the two predominate cleavages that meet at 87 degrees. A splintery appearance is caused by intersection of the two prismatic cleavages with a well developed basal parting.
Topaz	Occurs as well developed prismatic crystals in radiating and columnar aggregates. Also found in granular masses. Striations are oriented parallel to the c-axis. Colourless, white, pale blue, yellow, yellow-brown and orange. Luster is vitreous, transparent to translucent and hardness 8. One perfect cleavage on {001}. Massive white topaz is difficult to distinguish from quartz particularly if both minerals are transparent. Topaz may be variably replaced by fine-grained muscovite due to interaction with hydrothermal fluids.
Tourmaline group	Habit is typically prismatic and striated parallel to the long axis. Cross-sections are a distinctive rounded triangular shape. Also occurs in fibrous and massive aggregates. Colour is quite variable but is most commonly black to brown in Superior Province peraluminous granites and pegmatites. Also pink, green, blue or colourless in highly evolved pegmatites. Luster is vitreous, hardness 7 to 7.5. No cleavage present.
Wodginite	Red-brown, dark brown and black; present as sphenoidal and irregular grains generally between 1 and 10 mm diameter. Submetallic luster. Difficult to recognize in field especially when fine-grained and intergrown with other black Ta-Nb-bearing minerals. Recognition thus is largely dependent upon electron microscope analysis.
Zircon	Red, red-orange, red-brown, yellow-brown, brown. Typically occurs as small euhedral crystals that are vitreous, greasy to adamantine. Transparent to translucent. Hardness 7.5.

Metric Conversion Table

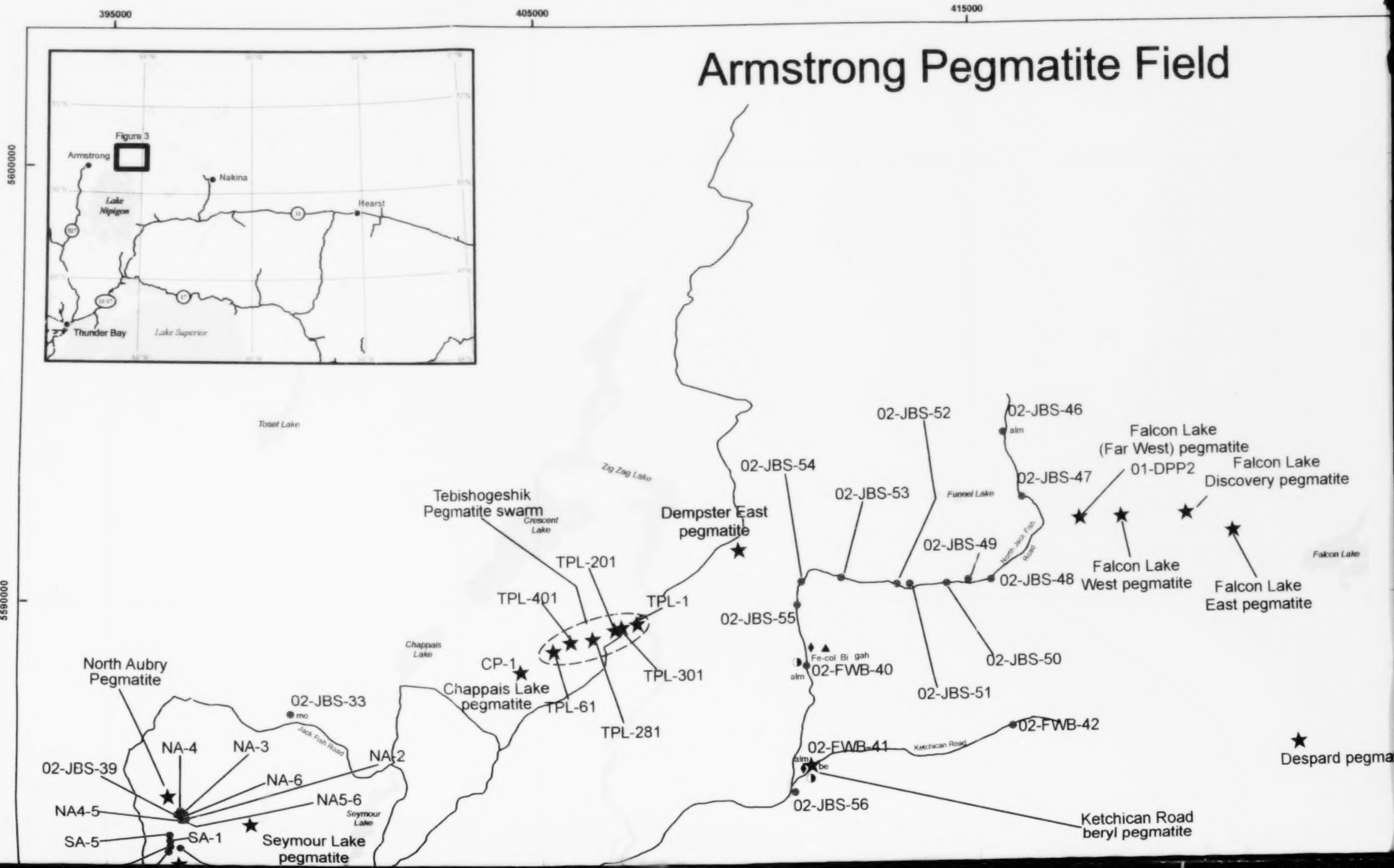
Conversion from SI to Imperial			**Conversion from Imperial to SI**		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
			LENGTH		
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
			AREA		
1 cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
			VOLUME		
1 cm^3	0.061 023	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.307 951	cubic yards	1 cubic yard	0.764 554 86	m^3
			CAPACITY		
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
			MASS		
1 g	0.035 273 962	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 747	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 622 6	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.102 311 3	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 90**	t
			CONCENTRATION		
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	Multiplied by	
1 ounce (troy) per ton (short)	31.103 477	grams per ton (short)
1 gram per ton (short)	0.032 151	ounces (troy) per ton (short)
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note: Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.

Figure 3. Location of rare-element pegmatites, bulk rock, bulk mineral and electron microprobe compositions from the western part of the Armstrong pegmatite field. Universal Transverse Mercator (UTM) co-ordinates are provided in North American Datum 1983 (NAD83), Zone 16.


395000
405000
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5600000
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Armstrong Pegmatite Field
Figure 3
Armstrong
Nakina
Hearst
Lake Nipigon
Thunder Bay
Lake Superior
11
17
11/17
527
Toset Lake
Zig Zag Lake
Crescent Lake
Chappais Lake
Funnel Lake
Falcon Lake
Seymour Lake
Jack Fish Road
North Jack Fish Road
Ketchican Road
02-JBS-46
alm
02-JBS-52
02-JBS-47
Falcon Lake (Far West) pegmatite
01-DPP2
Falcon Lake Discovery pegmatite
02-JBS-54
02-JBS-53
Tebishogeshik Pegmatite swarm
Dempster East pegmatite
02-JBS-49
02-JBS-48
Falcon Lake West pegmatite
Falcon Lake East pegmatite
TPL-201
TPL-401
TPL-1
02-JBS-55
TPL-301
Fe-col
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alm
02-FWB-40
02-JBS-50
02-JBS-51
CP-1
Chappais Lake pegmatite
TPL-61
TPL-281
North Aubry Pegmatite
02-JBS-33
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02-FWB-41
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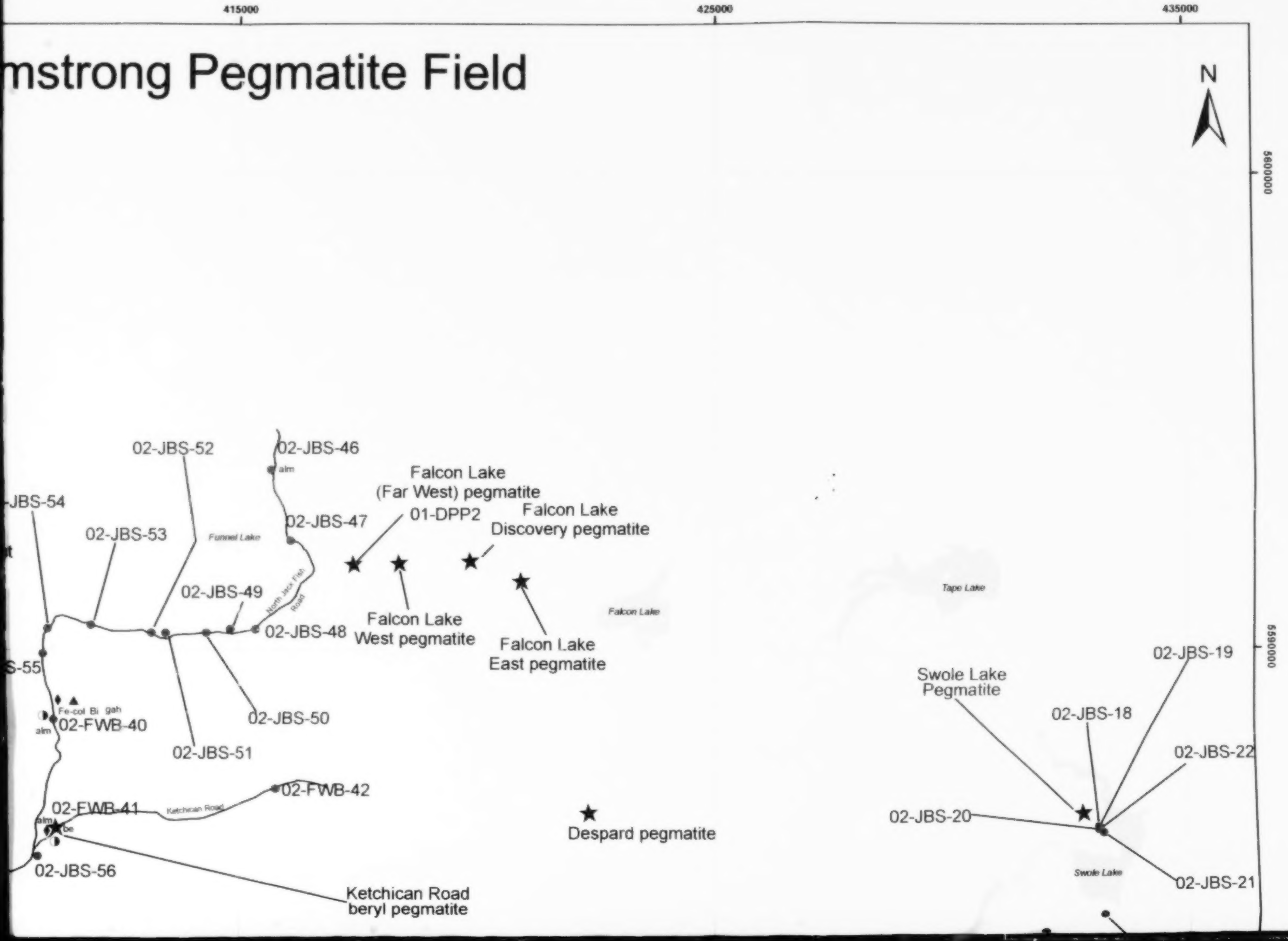
NA-3
NA-2
02-JBS-39
NA-6
NA5-6
NA4-5
SA-5
SA-1
Seymour Lake pegmatite
02-JBS-56
Ketchican Road beryl pegmatite

ns from the western part of the Armstrong
ican Datum 1983 (NAD83), Zone 16.


415000
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Falcon Lake
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-JBS-54
02-JBS-47
02-JBS-53
Funnel Lake
North Jack Fish Road
02-JBS-49
Falcon Lake
West pegmatite
Falcon Lake
02-JBS-48
Falcon Lake
East pegmatite
Tape Lake
S-55
Fe-col
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02-FWB-40
02-JBS-50
02-JBS-51
02-FWB-42
02-FWB-41
Ketchican Road
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02-JBS-56
Ketchican Road
beryl pegmatite
Swole Lake
Pegmatite
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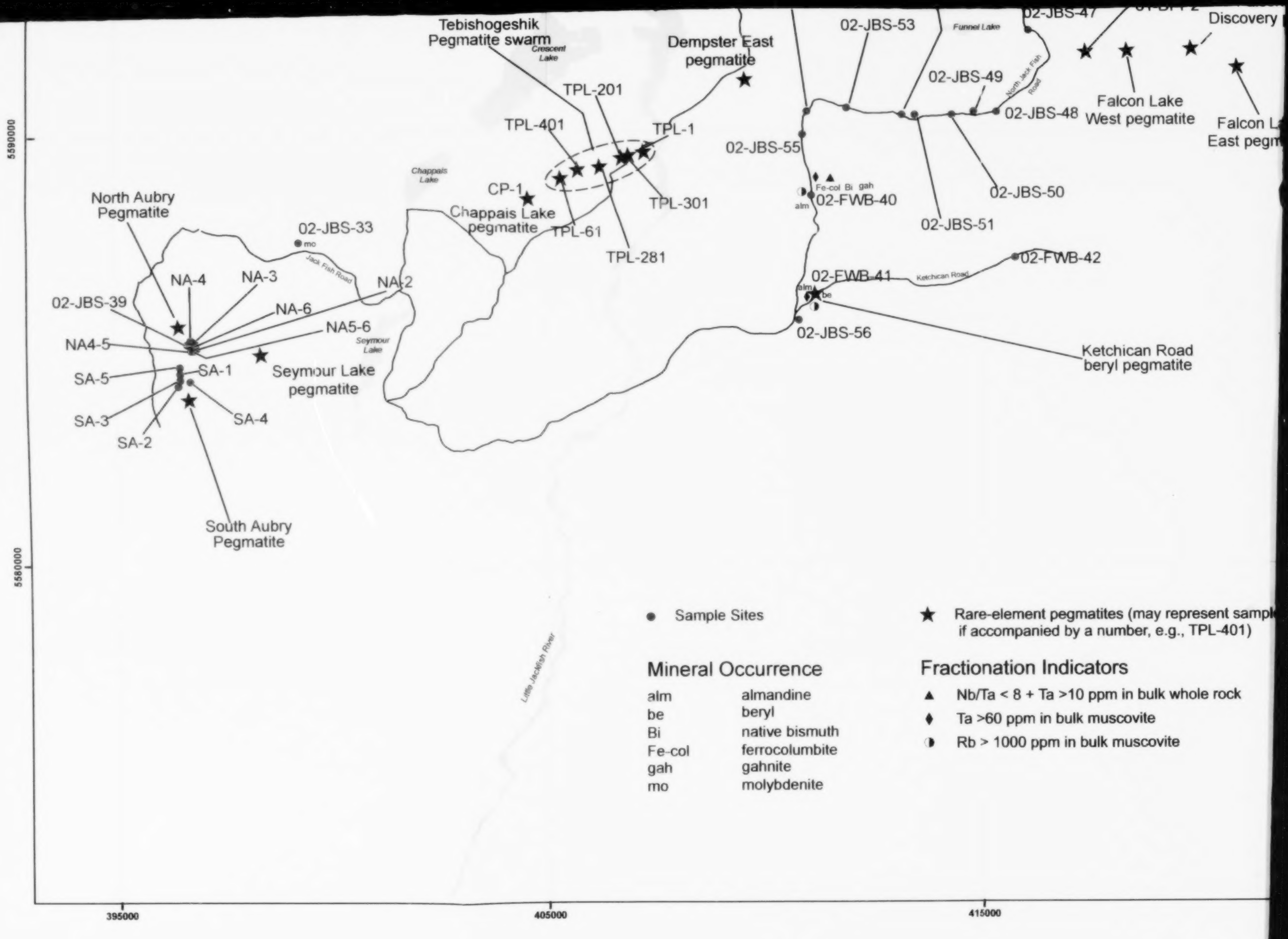
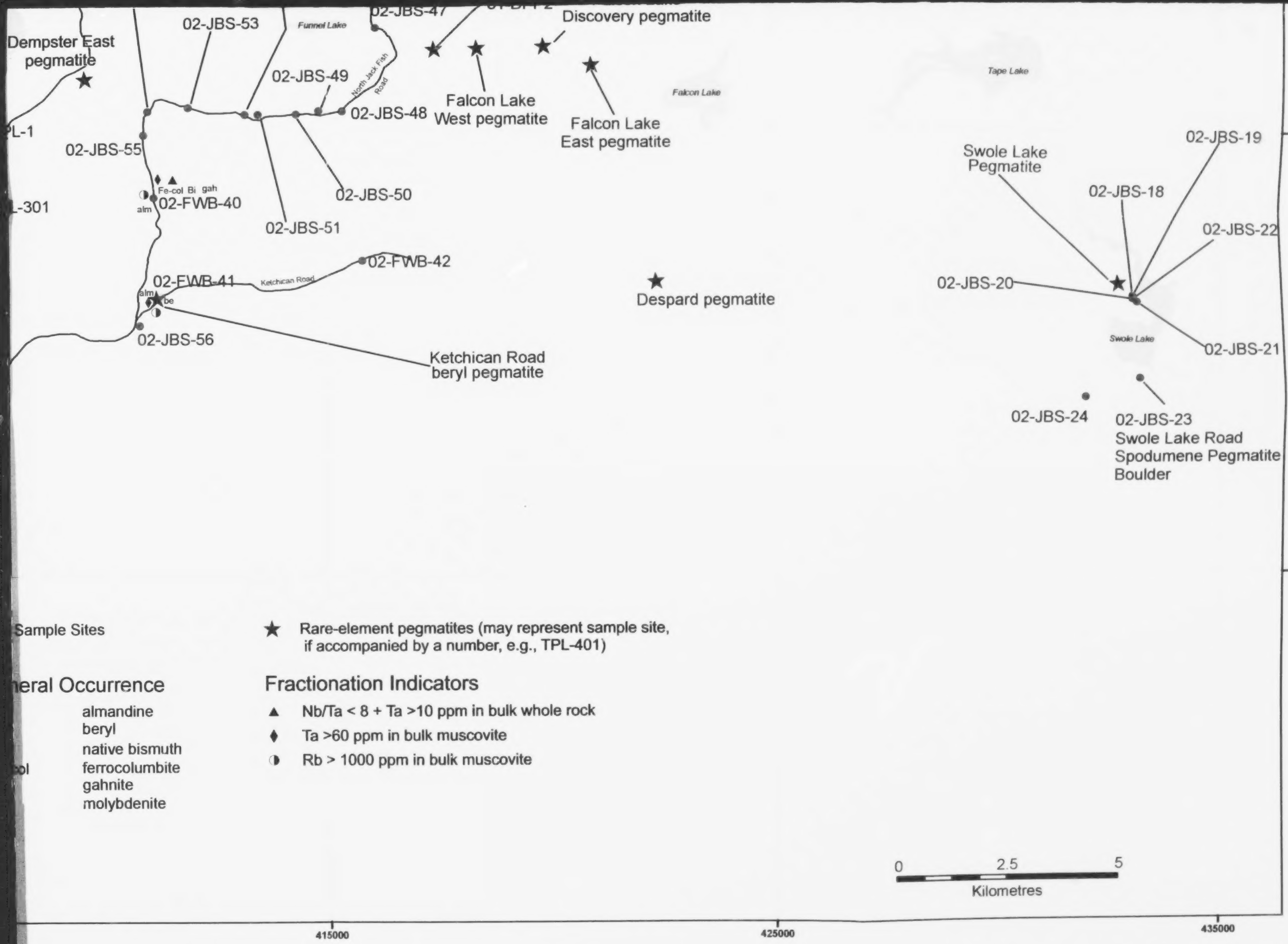
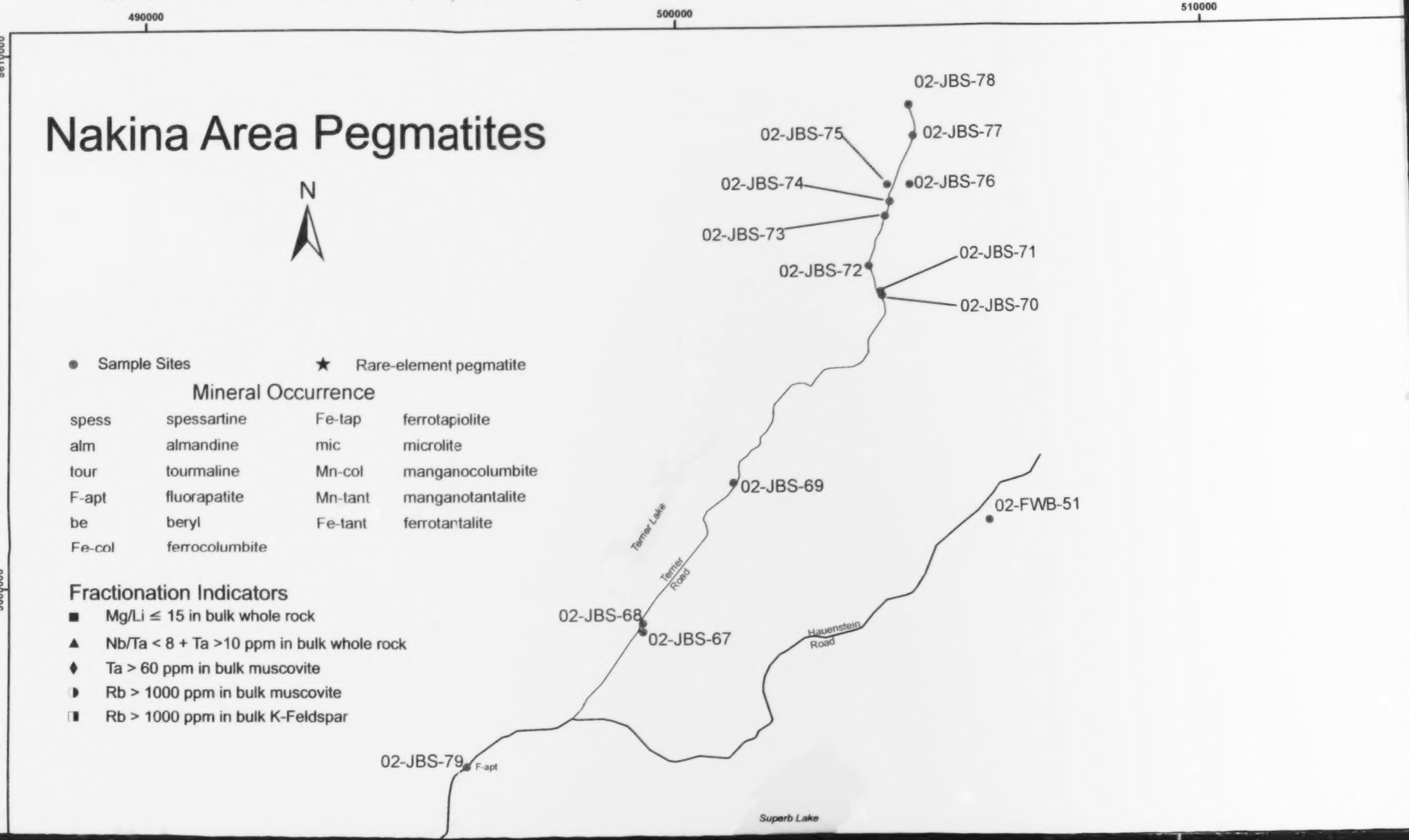
02-JBS-22
02-JBS-20
Swole Lake
02-JBS-21


Tebishogeshik Pegmatite swarm
Crescent Lake
Dempster East pegmatite
02-JBS-53
Funnel Lake
02-JBS-47
Discovery
02-JBS-49
North Jack Fish Road
Falcon Lake West pegmatite
02-JBS-48
Falcon L
East pegm
TPL-201
TPL-401
TPL-1
02-JBS-55
Chappais Lake
CP-1
Chappais Lake pegmatite
TPL-61
TPL-301
TPL-281
Fe-col
Bi
gah
alm
02-FWB-40
02-JBS-50
02-JBS-51
North Aubry Pegmatite
02-JBS-33
mo
Jack Fish Road
NA-4
NA-3
NA-2
02-JBS-39
NA-6
NA5-6
NA4-5
Seymour Lake
SA-5
SA-1
Seymour Lake pegmatite
SA-3
SA-4
SA-2
02-FWB-41
alm
be
Ketchican Road
02-FWB-42
02-JBS-56
Ketchican Road beryl pegmatite
South Aubry Pegmatite
Little Jackfish River
5590000
5580000
395000
405000
415000
● Sample Sites
★ Rare-element pegmatites (may represent sampl if accompanied by a number, e.g., TPL-401)
Mineral Occurrence
alm almandine
be beryl
Bi native bismuth
Fe-col ferrocolumbite
gah gahnite
mo molybdenite
Fractionation Indicators
▲ Nb/Ta < 8 + Ta >10 ppm in bulk whole rock
♦ Ta >60 ppm in bulk muscovite
◐ Rb > 1000 ppm in bulk muscovite

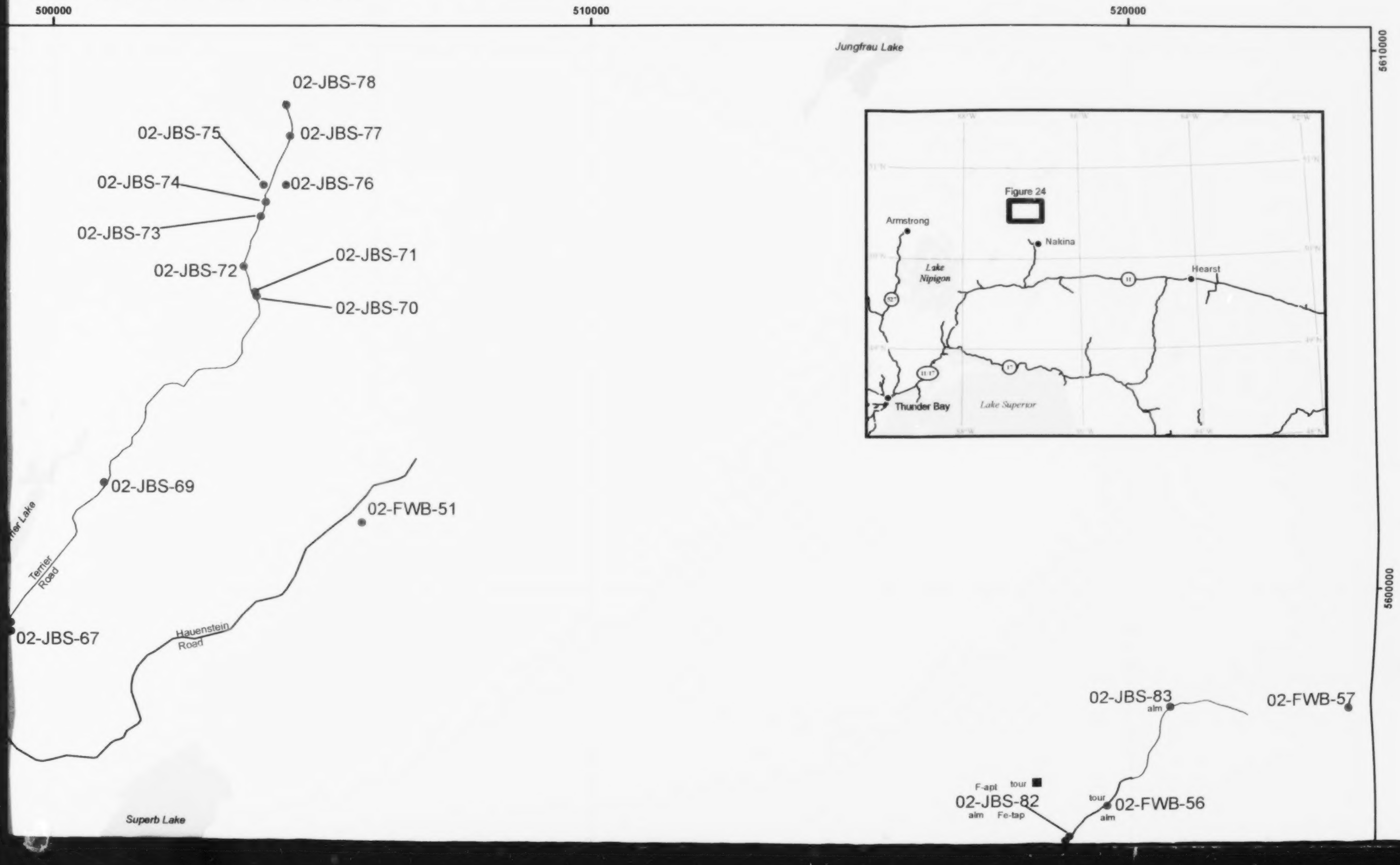

Dempster East pegmatite
PL-1
L-301
02-JBS-53
Funnel Lake
02-JBS-47
Discovery pegmatite
02-JBS-49
North Jack Fish Road
02-JBS-48
Falcon Lake West pegmatite
Falcon Lake East pegmatite
Falcon Lake
Tape Lake
02-JBS-55
Fe-col
Bi
gah
alm
02-FWB-40
02-JBS-50
02-JBS-51
02-FWB-42
02-FWB-41
Ketchican Road
be
02-JBS-56
Ketchican Road beryl pegmatite
Despard pegmatite
Swole Lake Pegmatite
02-JBS-18
02-JBS-19
02-JBS-22
02-JBS-20
02-JBS-21
Swole Lake
02-JBS-24
02-JBS-23 Swole Lake Road Spodumene Pegmatite Boulder
5590000
5580000
415000
425000
435000
0
2.5
5
Kilometres
Sample Sites
★ Rare-element pegmatites (may represent sample site, if accompanied by a number, e.g., TPL-401)
eral Occurrence
almandine
beryl
native bismuth
col ferrocolumbite
gahnite
molybdenite
Fractionation Indicators
▲ Nb/Ta < 8 + Ta >10 ppm in bulk whole rock
♦ Ta >60 ppm in bulk muscovite
◑ Rb > 1000 ppm in bulk muscovite

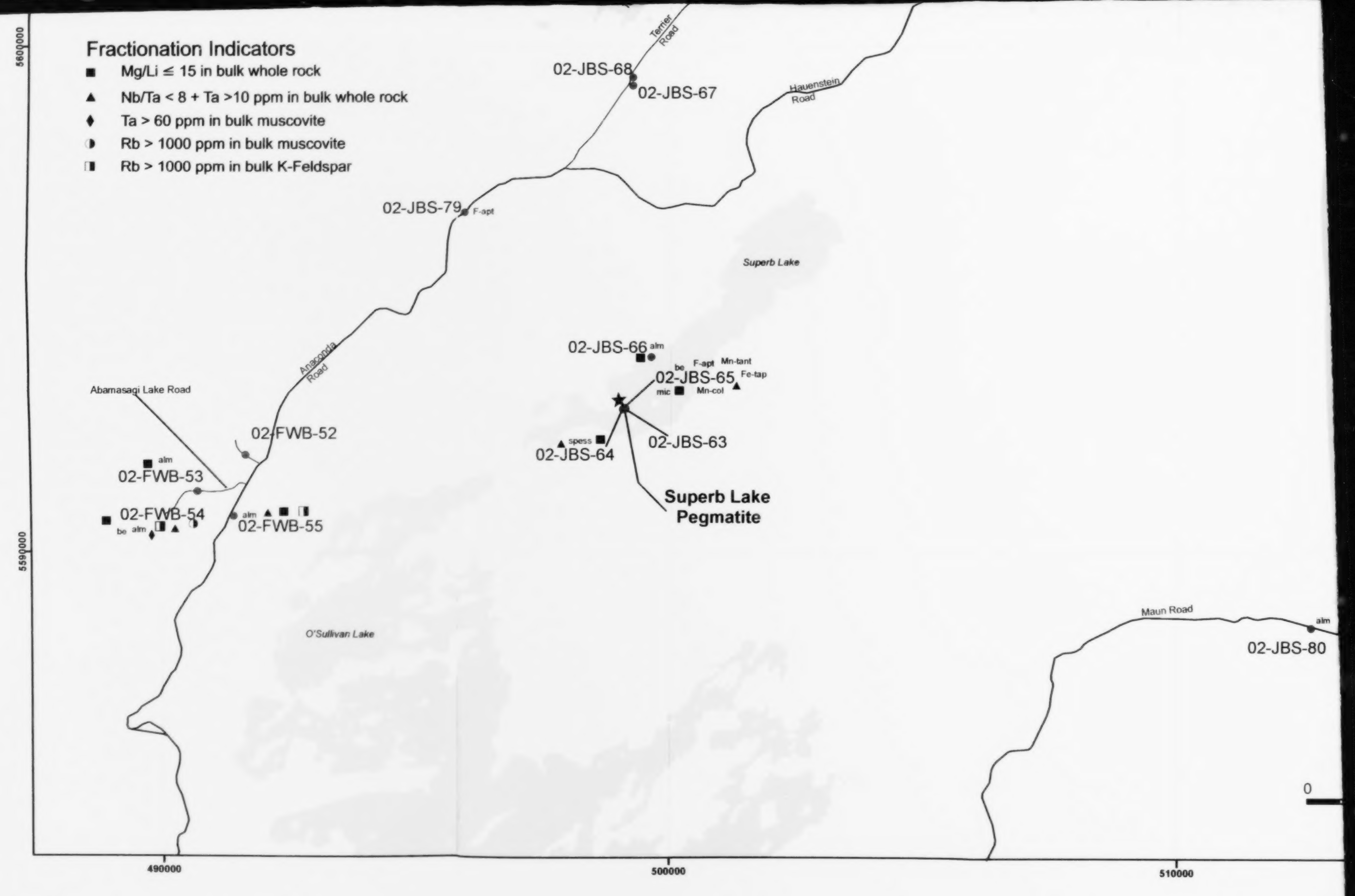
Accompanies OFR 6195

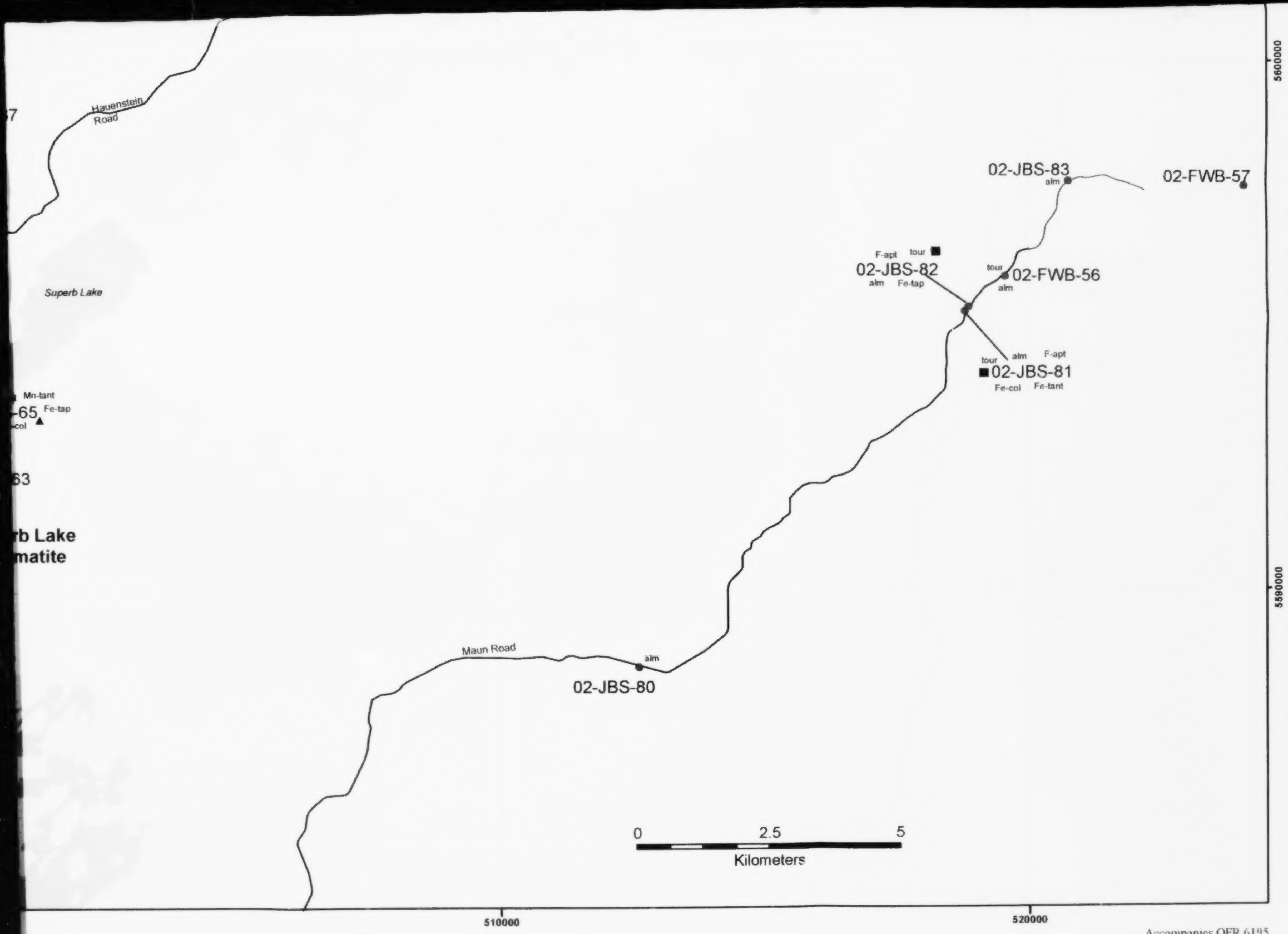
Figure 24. Location of bulk rock and mineral and electron microprobe compositions in the English River–Wabigoon subprovincial boundary zone north of Nakina. Universal Transverse Mercator (UTM) co-ordinates are provided in North American Datum 1983 (NAD83), Zone 16.


490000
500000
510000
5610000
5600000
Nakina Area Pegmatites
N
02-JBS-78
02-JBS-77
02-JBS-75
02-JBS-74
02-JBS-76
02-JBS-73
02-JBS-72
02-JBS-71
02-JBS-70
02-JBS-69
02-FWB-51
Terner Lake
Terner Road
02-JBS-68
02-JBS-67
Hauenstein Road
02-JBS-79
F-apt
Superb Lake
● Sample Sites
★ Rare-element pegmatite
Mineral Occurrence
spess spessartine
alm almandine
tour tourmaline
F-apt fluorapatite
be beryl
Fe-col ferrocolumbite
Fe-tap ferrotapiolite
mic microlite
Mn-col manganocolumbite
Mn-tant manganotantalite
Fe-tant ferrotantalite
Fractionation Indicators
■ Mg/Li ≤ 15 in bulk whole rock
▲ Nb/Ta < 8 + Ta >10 ppm in bulk whole rock
♦ Ta > 60 ppm in bulk muscovite
◑ Rb > 1000 ppm in bulk muscovite
◨ Rb > 1000 ppm in bulk K-Feldspar

the English River–Wabigoon subprovincial boundary zone north
d in North American Datum 1983 (NAD83), Zone 16.

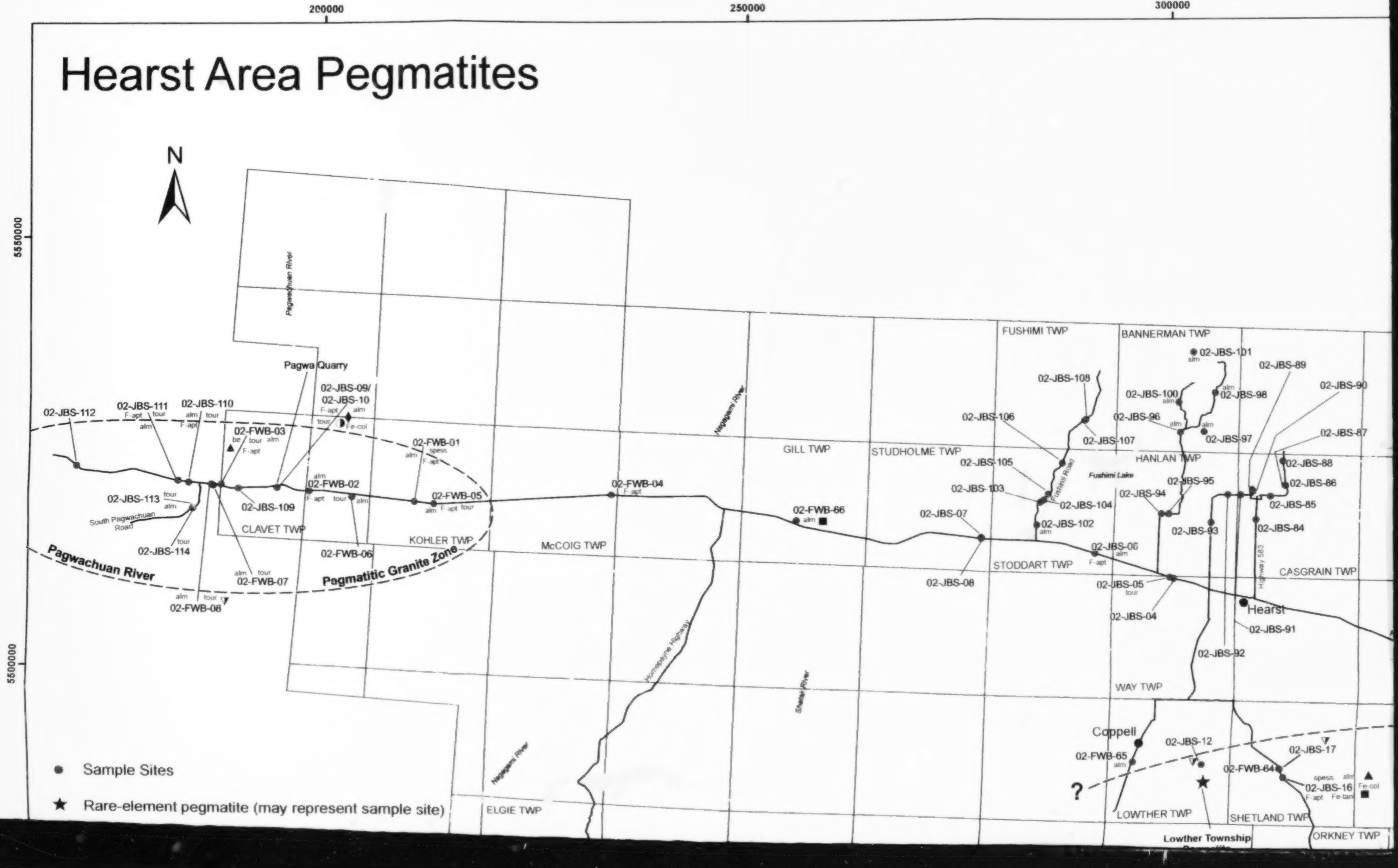

500000
510000
520000
5610000
5600000
Jungfrau Lake
02-JBS-78
02-JBS-77
02-JBS-75
02-JBS-76
02-JBS-74
02-JBS-73
02-JBS-72
02-JBS-71
02-JBS-70
02-JBS-69
02-FWB-51
rier Lake
Terrier Road
02-JBS-67
Hauenstein Road
Superb Lake
02-JBS-83
alm
02-FWB-57
F-apt
tour
02-JBS-82
alm
Fe-tap
tour
02-FWB-56
alm
Figure 24
Armstrong
Nakina
Lake Nipigon
Hearst
11
527
11/17
17
Thunder Bay
Lake Superior


Fractionation Indicators
■ Mg/Li ≤ 15 in bulk whole rock
▲ Nb/Ta < 8 + Ta >10 ppm in bulk whole rock
♦ Ta > 60 ppm in bulk muscovite
◑ Rb > 1000 ppm in bulk muscovite
◨ Rb > 1000 ppm in bulk K-Feldspar
Terrier Road
Hauenstein Road
Anaconda Road
Abamasagi Lake Road
Maun Road
Superb Lake
O'Sullivan Lake
02-JBS-68
02-JBS-67
02-JBS-79
F-apt
02-JBS-66
alm
be
F-apt
Mn-tant
02-JBS-65
Fe-tap
mic
Mn-col
spess
02-JBS-64
02-JBS-63
Superb Lake Pegmatite
02-FWB-52
alm
02-FWB-53
02-FWB-54
be
alm
alm
02-FWB-55
alm
02-JBS-80
0
5600000
5590000
490000
500000
510000

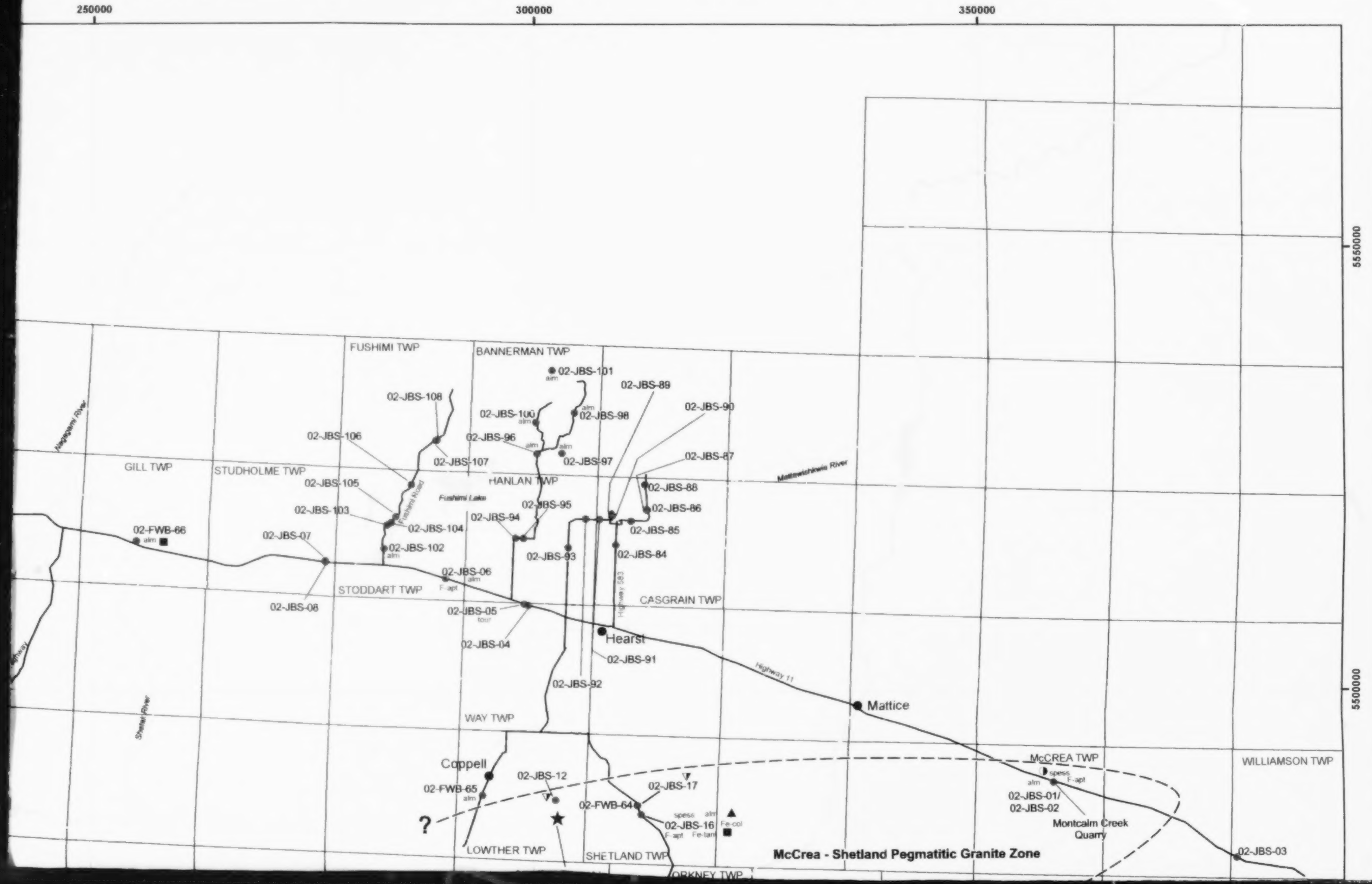

Hauenstein Road
Superb Lake
rb Lake
matite
Mn-tant
-65
Fe-tap
-col
63
02-JBS-83
alm
02-FWB-57
F-apt
tour
02-JBS-82
alm
Fe-tap
tour
02-FWB-56
alm
tour
alm
F-apt
02-JBS-81
Fe-col
Fe-tant
Maun Road
alm
02-JBS-80
0
2.5
5
Kilometers
5600000
5590000
510000
520000

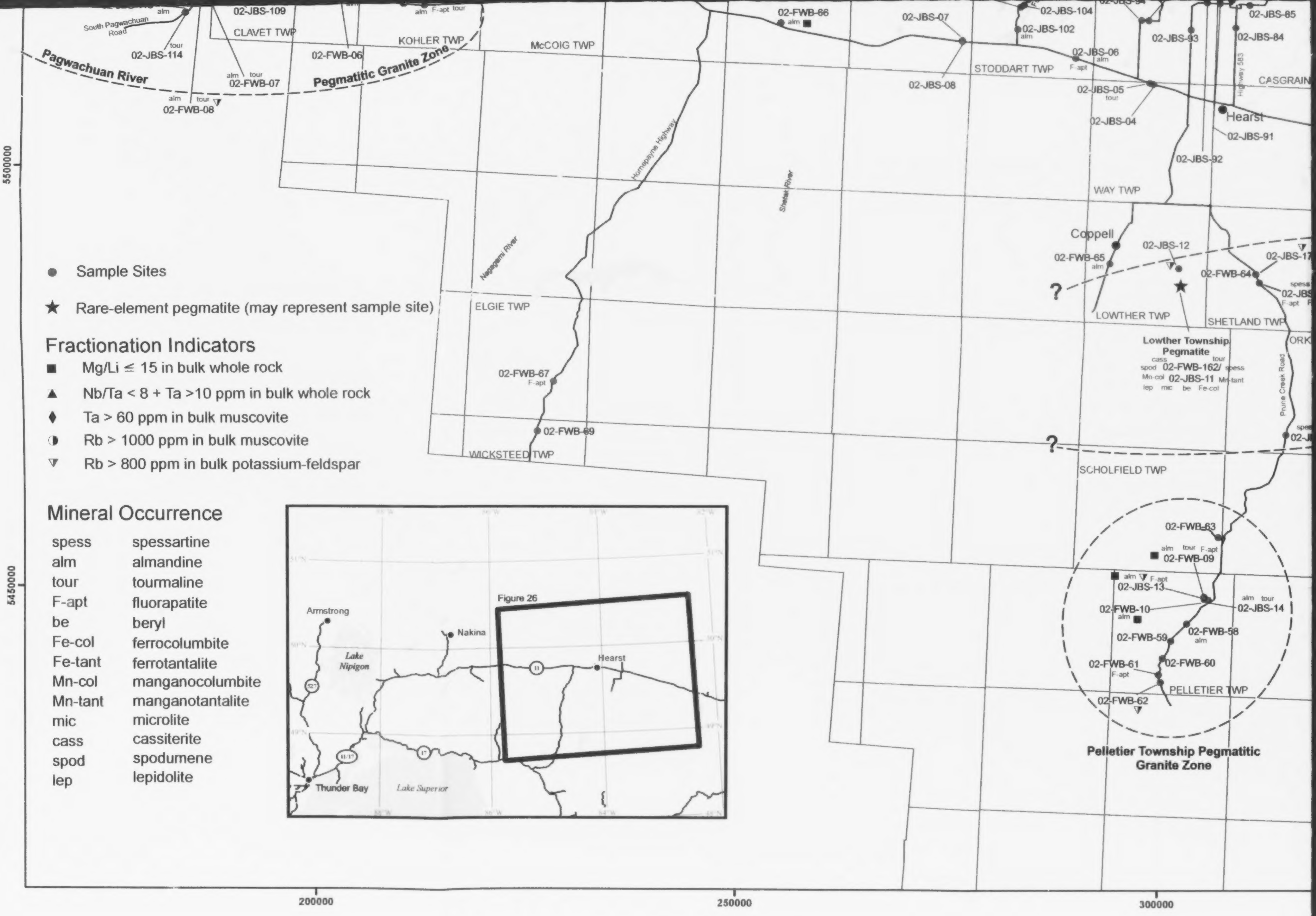
Accompanies OFR 6195

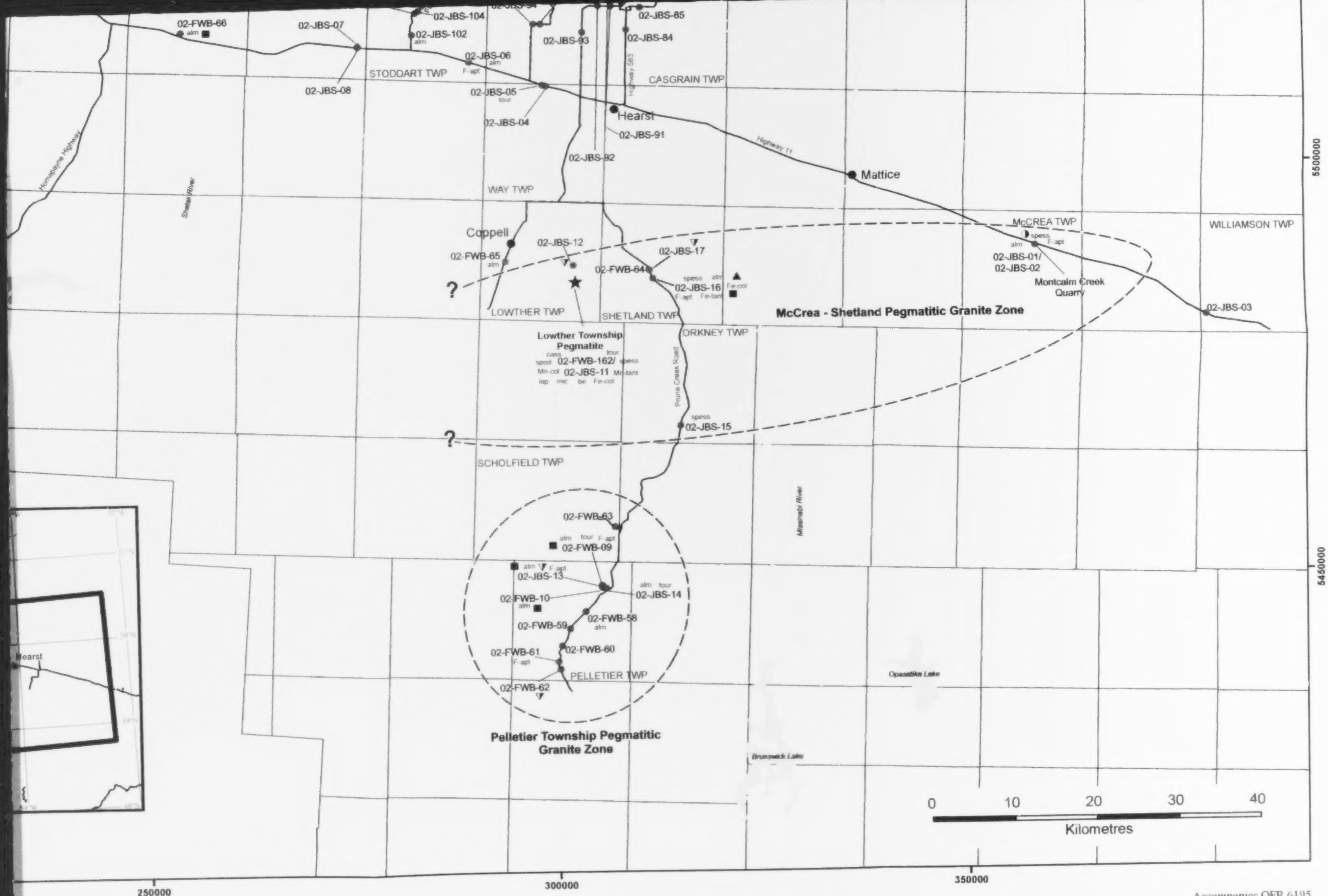
Figure 26. Location of bulk rock and mineral and electron microprobe compositions in the Quetico Subprovince of the Hearst area. Universal Transverse Mercator (UTM) co-ordinates are provided in North American Datum 1983 (NAD83), Zone 17.


Hearst Area Pegmatites
200000
250000
300000
5550000
5500000
N
Pagwachuan River
Pagwa Quarry
Pegmatitic Granite Zone
South Pagwachuan Road
CLAVET TWP
KOHLER TWP
McCOIG TWP
GILL TWP
STUDHOLME TWP
FUSHIMI TWP
BANNERMAN TWP
HANLAN TWP
STODDART TWP
CASGRAIN TWP
WAY TWP
LOWTHER TWP
SHETLAND TWP
ORKNEY TWP
ELGIE TWP
Nagagami River
Shekak River
Hornepayne Highway
Fushimi Road
Fushimi Lake
Highway 583
Hearst
Coppell
Lowther Township Pegmatite
?
02-JBS-112
02-JBS-111
02-JBS-110
02-JBS-113
02-JBS-114
02-JBS-109
02-JBS-09/
02-JBS-10
02-FWB-03
02-FWB-02
02-FWB-01
02-FWB-05
02-FWB-06
02-FWB-07
02-FWB-08
02-FWB-04
02-FWB-66
02-JBS-07
02-JBS-08
02-JBS-108
02-JBS-106
02-JBS-107
02-JBS-105
02-JBS-103
02-JBS-104
02-JBS-102
02-JBS-101
02-JBS-100
02-JBS-98
02-JBS-96
02-JBS-97
02-JBS-95
02-JBS-94
02-JBS-93
02-JBS-89
02-JBS-90
02-JBS-87
02-JBS-88
02-JBS-86
02-JBS-85
02-JBS-84
02-JBS-06
02-JBS-05
02-JBS-04
02-JBS-91
02-JBS-92
02-JBS-12
02-JBS-17
02-JBS-16
02-FWB-65
02-FWB-64
F-apt
tour
alm
be
spess
Fe-col
Fe-tan
● Sample Sites
★ Rare-element pegmatite (may represent sample site)

uetico Subprovince of the Hearst area.
can Datum 1983 (NAD83), Zone 17.


250000
300000
350000
5550000
5500000
FUSHIMI TWP
BANNERMAN TWP
GILL TWP
STUDHOLME TWP
HANLAN TWP
STODDART TWP
CASGRAIN TWP
WAY TWP
LOWTHER TWP
SHETLAND TWP
ORKNEY TWP
McCREA TWP
WILLIAMSON TWP
Nagagami River
Shekak River
Mattawishkwia River
Fushimi Lake
Fushimi Road
Highway 583
Highway 11
Highway
Hearst
Mattice
Coppell
02-JBS-101
alm
02-JBS-89
02-JBS-90
02-JBS-108
02-JBS-100
02-JBS-98
02-JBS-96
02-JBS-97
02-JBS-106
02-JBS-107
02-JBS-87
02-JBS-88
02-JBS-105
02-JBS-95
02-JBS-86
02-JBS-103
02-JBS-104
02-JBS-94
02-JBS-85
02-FWB-66
02-JBS-07
02-JBS-102
02-JBS-93
02-JBS-84
02-JBS-06
F-apt
02-JBS-08
02-JBS-05
tour
02-JBS-04
02-JBS-91
02-JBS-92
02-JBS-12
02-FWB-65
02-JBS-17
02-FWB-64
02-JBS-16
spess
Fe-col
Fe-tant
?
02-JBS-01/
02-JBS-02
Montcalm Creek
Quarry
02-JBS-03
McCrea - Shetland Pegmatitic Granite Zone


02-JBS-109
alm
South Pagwachuan Road
CLAVET TWP
tour
02-JBS-114
Pagwachuan River
alm tour
02-FWB-07
alm tour
02-FWB-08
02-FWB-06
KOHLER TWP
Pegmatitic Granite Zone
McCOIG TWP
02-FWB-66
alm
02-JBS-07
02-JBS-08
STODDART TWP
02-JBS-104
02-JBS-102
alm
02-JBS-06
alm
F-apt
02-JBS-05
tour
02-JBS-04
02-JBS-93
02-JBS-85
02-JBS-84
Highway 583
CASGRAIN
Hearst
02-JBS-91
02-JBS-92
Hornepayne Highway
Shekak River
Nagagami River
WAY TWP
Coppell
02-FWB-65
alm
02-JBS-12
02-FWB-64
02-JBS-17
spess
02-JBS
F-apt
?
LOWTHER TWP
SHETLAND TWP
ELGIE TWP
Lowther Township Pegmatite
cass tour
spod 02-FWB-162/ spess
Mn-col 02-JBS-11 Mn-tant
lep mic be Fe-col
Prune Creek Road
02-FWB-67
F-apt
02-FWB-69
WICKSTEED TWP
?
SCHOLFIELD TWP
02-JB
● Sample Sites
★ Rare-element pegmatite (may represent sample site)
Fractionation Indicators
■ Mg/Li ≤ 15 in bulk whole rock
▲ Nb/Ta < 8 + Ta >10 ppm in bulk whole rock
♦ Ta > 60 ppm in bulk muscovite
◑ Rb > 1000 ppm in bulk muscovite
▽ Rb > 800 ppm in bulk potassium-feldspar
Mineral Occurrence
spess spessartine
alm almandine
tour tourmaline
F-apt fluorapatite
be beryl
Fe-col ferrocolumbite
Fe-tant ferrotantalite
Mn-col manganocolumbite
Mn-tant manganotantalite
mic microlite
cass cassiterite
spod spodumene
lep lepidolite
Figure 26
Armstrong
Nakina
Lake Nipigon
Hearst
11
527
11/17
17
Thunder Bay
Lake Superior
02-FWB-63
alm tour F-apt
02-FWB-09
alm F-apt
02-JBS-13
alm tour
02-JBS-14
02-FWB-10
alm
02-FWB-59
02-FWB-58
alm
02-FWB-61
F-apt
02-FWB-60
PELLETIER TWP
02-FWB-62
Pelletier Township Pegmatitic Granite Zone
5500000
5450000
200000
250000
300000


02-FWB-66
alm
02-JBS-07
02-JBS-104
02-JBS-102
alm
02-JBS-94
02-JBS-85
02-JBS-84
02-JBS-93
02-JBS-06
alm
F-apt
STODDART TWP
02-JBS-08
02-JBS-05
tour
02-JBS-04
CASGRAIN TWP
Highway 583
Hearst
02-JBS-91
02-JBS-92
Highway 11
Mattice
Hornepayne Highway
Shekak River
WAY TWP
Coppell
02-FWB-65
alm
02-JBS-12
02-JBS-17
02-FWB-64
spess
alm
02-JBS-16
Fe-col
F-apt
Fe-tant
?
LOWTHER TWP
SHETLAND TWP
ORKNEY TWP
McCREA TWP
spess
F-apt
alm
02-JBS-01/
02-JBS-02
Montcalm Creek
Quarry
WILLIAMSON TWP
02-JBS-03
McCrea - Shetland Pegmatitic Granite Zone
Lowther Township
Pegmatite
cass
tour
spod
02-FWB-162/
spess
Mn-col
02-JBS-11
Mn-tant
lep
mic
be
Fe-col
Prune Creek Road
spess
02-JBS-15
?
SCHOLFIELD TWP
Missinaibi River
02-FWB-63
alm
tour
F-apt
02-FWB-09
alm
F-apt
02-JBS-13
alm
tour
02-JBS-14
02-FWB-10
alm
02-FWB-58
alm
02-FWB-59
02-FWB-60
02-FWB-61
F-apt
PELLETIER TWP
02-FWB-62
Pelletier Township Pegmatitic
Granite Zone
Opasatika Lake
Brunswick Lake
Hearst
0
10
20
30
40
Kilometres
5500000
5450000
250000
300000
350000

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